DEVELOPMENT OF A KEROSINE FIRED INCUBATOR WITH TEMPERATURE CONTROL

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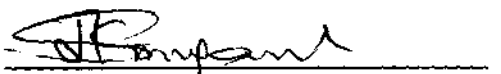
DECLARATION

I hereby declare that this thesis is written by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree. All sources of information which are not my own originals were duly acknowledged by means of references.



K.J. SIMONYAN

DEDICATION

I dedicate this work to God Almighty for granting me the Grace and Mercy to begin and finish this course of study

AND

To my son OLORUNTOBI OLUWABORI, SIMONYAN who was born during the period of this study.

CERTIFICATION

This thesis entitled "DEVELOPMENT OF A KEROSINE FIRED INCUBATOR WITH TEMPERATURE CONTROL" by the author SIMONYAN, KAYODE JOSHUA meets the regulations governing the award of degree of master of science (Agricultural Engineering) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

A low cost kerosine fired incubator with heating from below was developed.

Various methods of internal temperature control inside the incubator were explored. Airtight sealed diaphramic control was not possible due to the closeness of the solubility index of the volatile liguids and locally available adhesives.

The sensitivity of the bimetallic strip was low in the temperature range of the incubator. (35°C - 39°C)

An electromechanical method of temperature control using electromagnet was designed and applied to circumvent the above problems.

The highest average daily dry bulb temperature value inside the incubator was 38°C while the lowest value was 35°C during the period of incubation.

The highest average daily dry bulb temperature inside the room was 31°C while the lowest was 23°C.

The high relative humidity value obtained for the period of incubation was 60% while the lowest value was 45%.

Relative humidity was negatively related to the incubator temperature while the room temperature was positively related to the incubator temperature.

Analysis shows that there was no statistically significant linear relationship between the incubator

temperature and the room temperature at 5% level of significance.

Also there was no statistically linear relationship between the incubator humidity and the room temperature at 5% level of significance. And there was no statistically significant relationship between the incubator temperature, the room humidity and the room temperature at 5% level of significance.

The hatching result gave a hatchability of 86%, 63% and 57% for group I, II, and III respectively, for the third experiment which show that the hatchability decreased with the days of storage before incubation.

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LIST OF SYMBOLS

NU	Nusselt (Dimensionless)
Pr	Prandt (Dimensionless)
Gr	Grashof (Dimensionless)
h	Convective heat transfer coefficient $W/_{m2}{}^{0}C$
k	Thermal conductivity $W/_{m}{}^{0}C$
L	Characteristic Length of the flow channel
g	Acceleration due to gravity 9-81 m/s^2
B	Coefficient of thermal expansion
U	Overall heat transfer coefficient W/m^2
DT	Overall temperature difference
Q	Total heat transfer rate W/m^2
q	Heat flux W/m^2
m	Mass flow rate kg/s
T,t	Temperature ^{0}C
&	Thermal diffussivity m^2s
P	Atmospheric pressure, kpa
W	Humidity Ratio kg/kg
C_p	Specific heat capacity at constant pressure J c^{-1} g^{-1}
f_p	Density kg/m^3
D.S	Degree of saturation
F	Force N
T_i	Current A
H	Enthalpy KJ/kg
R	Thermal Resistance
A	Area through which heat is conducted m^2

M	Mass (kg)
Q	Volume flow rate m^3/s
V	Specific volume m^3/kg
C_v	Specific heat capacity at constant volume
F	Correction Factor
DT_{im}	Logarithmic Mean Temperature Difference ^0C
A_t	Free air inlet and onlet area, m^2
h_t	Height from inlets to outlets, m
M_w	Mass of water vapour removed kg
A_c	Psychrometric constant, $^0C^{-1}$
LW (t*)	Latent heat of vapourization of water at the wet-bulb temperature Jg^{-1}
t*	Wet bulb temperature ^0C
n	Ratio of mass of water to mass of dry air
Σ	Summation
C_{pa}	Specific heat of dry air $JC^{-1}g^{-1}$
C_{pv}	Specific heat of water vapor $Jc^{-1}g^{-1}$
P_s^*	Saturation vapor pressure, kpa
W_s^*	Humidity Ratio at the wet-bulb temperature
*	Significant at 5% level of significance
**	Significant at 1% level of significance
$ μ	Fluid viscosity
r	Correlation coefficient
t	Student t test

LIST OF ABBREVIATIONS

D.B	Dry Bulb Temperature ^{0}C
W.B	Wet Bulb Temperature ^{0}C
R.H	Relative Humidity (%)
C.V	Coefficient of variation (%)
D.P	Dew point Temperature
S.D	Standard Deviation
N.S	Not Significant
D.F	Degree of freedom
SS	Sum of Squares
MS	Mean of square = SS/Df
LMTD	Logarithmic Mean Temperature Difference ^{0}C
IC	Incubator Condition
RC	Room Condition

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CHAPTER 1

INTRODUCTION

Poultry Products have taken an important place in the nutrition of human race. They are very important sources of protein, minerals and vitamins. Eggs from poultry is very palatable, easily digested and can be consumed in a variety of ways (FAO 1965). Poultry meat provides man with nutrients for growth, tissue replacement and weight control. Poultry meat has a lower fat content and it contains more protein than any other meat (Oluyemi and Roberts, 1988). Poultry enterprise provides employment than any other single enterprise since many people are involved in the feed production, distribution, marketing of the eggs and poultry meat (Say, 1987; FAO, 1965, Aywor and Hellins, 1956). A recent survey reveals an estimated population of 70.93 millions chickens as against 11.79 million ducks; 4.68 millions guinea fowl and 223,000 turkey in Nigeria (RIMS, 1992)

Of all the various aspects of poultry production, egg incubation for hatchery is the most intricate. Incubation of eggs may be by natural method whereby the hens sit on the eggs to provide the necessary environment for hatching or by artificial method where hatching is carried out with incubator.

A local breed hen lays about 50 eggs per year and hatches 27 to 28 eggs (Say, 1987). The hatching rate which is an average of 60% depends very much on the season and on the condition of the broody hen. Chicken production employing the natural method is very inadequate in relation with the demand for poultry products. Hatching of eggs by artificial incubation is a faster means to ensure increased production of poultry products in the country.

In recent years there have been increased importation of various types of incubators into the country. Heat for these incubators can be provided by electricity, kerosine, gas or coal fire. However, some problems have continued to militate against the successful operation of the electric incubators. Some of the problems are incessant disruption of electric power supply, lack of maintenance, lack of spare parts and low purchasing power of the small scale farmers. It is imperative therefore to encourage local capability in the manufacture of appropriate incubation equipment for the poultry industry.

Majority of the poultry products in the country are produced by the medium and small-scale farmers with less than 5,000 birds (Kekeocha, 1978). Their farms are mostly located in the rural areas where there is lack of basic infrastructures for successful operation of the highly sophisticated imported, large capacity incubators. Even where the basic infrastructures are available, they are inefficiently operated due to high cost of maintenance. This

is very risky and costly in such a highly sensitive undertaking like the incubation of eggs where the optimum conditions must be meticulously maintained.

A kerosine fired incubator appears to solve most of these problems. Kerosine is readily available, affordable and less flammable. Imported table type kerosine fired incubators and some locally made incubators are available in the country. The major difference is in the method of temperature regulation. While the imported kerosine types have automatic temperature control, the temperature in the locally made types must be regulated manually by the removal and replacement of the heat source at intervals. This is quite tasking, delicate and risky.

A control is therefore necessary to maintain the design conditions inside the incubator, to minimise the heat use, to keep the operation of the equipment at safe levels and to reduce the amount of human effort needed to operate and maintain the system, to obtain the best result from the incubator, the control must detect, monitor the control variables and regulate the performance.

Though some research work have been done on incubators in the country, there is a dearth of published information on the control of temperature of kerosine fired incubators developed in the country.

It is therefore pertinent to develop methods of controlling the temperature in a kerosine fired incubator for use in locality where electricity is not available.

The objectives of this research therefore are:

i) to develop a kerosine fired incubator with automatic temperature control using locally available materials

ii) to test the performance of the developed temperature control on the incubator.

CHAPTER 2

LITERATURE REVIEW

2.1 Physical Properties of Egg.

The knowledge of the physical properties of egg is vital to the design and operation of an incubator. Henderson (1957) gave some features of an average hen's egg that are relevant for engineering considerations. The features are listed in table 2.1.

Table 2.1: The engineering properties of a typical hen egg.

Properties	Values
Weight	58g
Diameter:	
Major	5.7 cm
Minor	4.2cm
Volume	53 ml
Surface Area	68.0 cm^2
Specific gravity	1.08 - 1.09
Specific heat	0.772

Source: Henderson (1957)

Henderson (1957) reported the percent weight of the component part of an egg as follows shell, 11%; albumen, 58% and yolk, 31%. He also reported that the average vapour pressure of egg is approximately that of pure water.

In a similar study, but reporting on the tropical condition, Oluyemi and Roberts (1988) found that the weight of the egg varies from flock to flock though it is lower in the tropics than in the temperate regions. They also reported that

the egg shell is on the average about 0.33 mm thick with percent weight of the structural component parts as albumen, 56-57%; yolk 32%; shell, 10.7% and shell membrane, 0.4%. This is almost in perfect agreement with the findings of Henderson (1957).

2.2 Methods of Incubation

Incubation may be achieved by natural method whereby a broody hen sits on the eggs to provide conducive environment necessary for embryonic development. The advantages associated with this method include low initial capital outlay and higher percentage of eggs which could be hatched if the conditions are satisfactory. However, the production from this method which depends on the condition of the broody hen is very low compared with the increasing demand for poultry products (Say, 1987; Aremu and Shiawoya, 1992).

The artificial method uses mechanical equipment to simulate the natural condition for incubation. The incubators available are of various sizes and operational mechanisms depending on the manufacturer. It offers the advantage of being readily available and also the ability to hatch a large amount of eggs. The various designs include hot air type, hot water type, natural convection or forced convection flow type (Van Wageningen and Meinderts, 1990; Ezekwe, 1979).

The hot air type heats up the cold air directly before entering into the incubator to heat the air inside the

incubator. In the hot water type, the water acts like a buffer on the temperature (Ezekwe, 1979). Phillips (1977) proposed that the hot water type maintains a more steady temperature than the hot air type.

The natural convection incubator type is mostly the table or flat incubator with capacity of 50-150 eggs. The transfer of heat within the incubator is due to buoyancy force derived from the change of temperature. The source of heat could be stove, kerosine lantern or electricity (Say, 1987; Ezekwe, 1979).

Forced or cabinet incubator type is larger as it can accommodate from a few hundreds to tens of thousands of eggs. The heat source is mostly electric with automatic controls for the temperature humidity and turning (Swanson, 1979; Drigers, 1980).

2.2.1 Factors Affecting Artificial Incubation.

Operating the incubator efficiently calls for definite set of conditions. Several factors that are vital to ensure successful hatching are discussed below.

Temperature is a very important factor for eggs to hatch. The embryonic development inside the egg shell is initiated by temperature rise which must be properly regulated to obtain a good hatch. According to Klers (1983), hatching of eggs is a physiological process which depends on the hatching time and environmental temperature. Embryos are very sensitive to an

increase in temperature above the optimum requirement. An increase in incubation temperature will result in decreased hatching time which result in an early hatch and damage to the chicks by the time they are placed in the brooder house. Low incubation temperature will delay or 'drag' the hatch resulting in a high incidence of live pips at pull time (Krueger, 1977; North, 1980 and Strong, 1979).

Several researchers have recommended different temperature ranges for incubation. Phillips (1977) recommended a temperature of 39.50°C for the first seven days, 39°C up till the 19th day and 38°C for the remaining period of incubation. Krueger (1977) recommended a temperature range between 37.2°C and 37.8°C while Oluyemi and Roberts (1988) reporting on the tropical condition recommended a temperature range of 37.2°C to 39.4°C for most satisfactory development of the embryos inside the incubator. While there is disparity with the exact temperature they however all agree that the exact temperature depends on the incubator type and on the age of the eggs inside the incubator.

Wilson and Ande (1980) reported the outcome of their study that temporary high temperatures early in incubation does not affect hatchability as much as they will later. They reported that exposure of 3-day old embryos to a temperature of 43.3°C for 12 hours caused the hatchability of fertile eggs to drop to about 50%. A decrease in hatchability was the same when 7 - day old embryos were subjected to 4 hours of 43.3°C

temperature and when 11- and 16 day - old embryos were stressed for 7 hours. Hatchability of embryos exposed at 19 days to high temperature was decreased more than 50% by 5 hours of heat stress. The chicks that did hatch from the eggs following severe heat stress had wiry down and they were usually weak and unable to stand. Due to incubation temperature that is higher than room temperature, evaporation takes place continually while eggs are incubating which results in weight loss. Jones (1978) noted that for a normal hatch, an egg should lose 11% to 12% of its weight during the first 18 days of incubation. A greater or lesser amount of evaporation affects the overall hatch, the quality and the appearance of the chicks.

The amount of egg moisture loss is determined by the relative humidity in the incubator which affect hatchability (Strong, 1979). Jones (1978) and Strong (1979) reported that high relative humidity lowers the weight loss and low relative humidity increases the weight loss. They noted that small eggs evaporate more rapidly than large ones and also that some breeds tend to have more porous eggs than other breeds and therefore evaporate more rapidly. The relative humidity inside the incubator thus has an important influence on the embryonic growth inside the egg. According to Krueger (1977), Krueger and Fanguy (1979) relative humidity controls the development and the size of the air cell that provides the chicks first life giving breath of oxygen when pipping process

begins. Low humidity during incubation results in excessive evaporation of the liquid content of the egg which results in a dry and difficult hatch. On the other hand, high humidity prevents sufficient evaporation from the eggs which result in oversized yolks that produce big, soft-belied chicks. The exact relative humidity for incubation depends on the type of the incubator and the age of the eggs. However it was suggested by Oluyemi and Roberts (1988) that a relative humidity of about 56-60% would cause the egg to lose between 11 and 13% of the initial weight of the egg (0.4g/day) over 18 day period of incubation. Phillips (1977) recommended a relative humidity of between 30 and 60% inside the incubator.

Embryonic development is dependent on a good supply of fresh air in the incubator since eggs are biological organisms. According to Jones (1975); Krueger (1977) and Jones (1978) for optimum hatchability and normal embryonic growth, it is necessary to provide an atmosphere in the incubators which has an oxygen content of 21%. They reported that air in the atmosphere at sea level up to 1000 metres above sea level has a natural oxygen content of 21%. Above 1000m, the oxygen content in the air decreases. Jones (1975) reported that air pressure within the incubator room is important because it affects the ventilation within the incubators. He observed that positive air pressure is created in a room when the volume of incoming air is greater than the volume of outgoing air. Negative air pressure is created when the outgoing

volume of air is greater than the incoming air. The pressure within the incubators will be the same as that of the incubator room, regardless of the air pressure outside the building. The volume of air flowing through the incubator from the room is critically important not only because of fresh air needs, but also for maintaining CO_2 levels, temperature and humidity at acceptable levels. Stewart (1980); Jones (1975) and Jones (1978) recommended that the air flow should be controlled by means of adjustable intake and outlet vents. Petzenhauser (1980) suggested three considerations in the selection of the inlet systems: (i) the inlet openings must be capable of adjusting with change of ventilation capacity by maintaining a uniform static pressure constantly; (ii) the inlet system must distribute the air uniformly throughout the structure; (iii) the inlet must have a significant influence on the vertical direction of the system of air at the point of entry. Jones (1975) then suggested that one cubic metre of fresh air per hour should be allowed for each 100 eggs under incubation and three (3) cubic metres of fresh air per hour for each 100 hatching eggs or 100 day old chicks for embryos during their final two days of incubation and also for chicks held in the hatchery awaiting despatch.

Jones (1978) reported that the process of embryonic development requires the expenditure of energy which is provided by the combustion of egg matter in oxygen derived

from the atmosphere surrounding the egg. The amount of oxygen required by the embryos increases with age. The embryo produces carbondioxide (CO_2) which it expels into the atmosphere surrounding the egg. Heat is also produced by the eggs during incubation. The total heat which depends on the number of egg under incubation increases with the embryo's age and its use of oxygen starting from 2-4 days of incubation at approximately 0.40 gram calorie per day per egg and ending with approximately 90 gram calorie per day at 19 days of incubation. Ventilation is needed to remove from the incubator ammonia, carbon dioxide and other obnoxious substances which arise as a result of respiration and spoilage of some eggs (Albright, 1980). Geise and Bond (1952); Giese and Ibrahim (1950); Giese and Downing (1950) ; Oluyemi and Roberts (1988); Krueger (1977) and Jones (1978) observed that high level of carbon dioxide that result from restrictive ventilation results in slow embryonic growth, increased embryonic abnormalities, weak chicks and reduced hatchability.

There have been numerous assertions on the effect of placement of eggs in the incubator on hatchability. Krueger (1977) advocated that eggs should be placed in trays with the larger ends up as this keeps the air cell in normal position and reduces malpositioned embryos. He observed that if the eggs are laid on their side or are small end up, the air cells probably will become loose, thereby reducing hatchability. This was confirmed by Klers (1983) who reported that placing

eggs with the small ends up are insidious but preventable cause of hatch reduction. He noted that putting the eggs with the small end up ruptures the extra embryonic membrane which causes lower hatchability of eggs. According to Laura and Renden (1979) the hatchability of broiler breeder eggs incubated for 11, 14 and 17 days with air cell pointed down had a significant decrease in hatchability. They reported that there was an increase in dead embryos at 18 to 20 days of incubation and the number of pipped but unhatched eggs also increase. Takeshita and McDaniel (1980) on their part observed that eggs incubated with the small end up had lower hatchability and chick weights than those incubated small end down or in a flat or horizontal position. They also reported that eggs in either small end up or flat position had a greater number of pips away from the air cell and a greater number of malposition than those with the small end down.

Hatching eggs must be turned during incubation if they are to hatch. As the embryonic development proceeds and the eggs age, the albumen becomes watery and the embryo floats. If the eggs are laid down on one side of the shell, the extra embryonic membrane and the embryos get stuck to the shell on the sides. Turning the eggs is therefore necessary to prevent the embryo from sticking to the inner membrane. While there is universal agreement by several authors on the benefits of turning eggs there is however disparity on the number of times to turn the eggs per day. Jones (1978) asserted that turning

of eggs is most critical through the first 9 days of incubation and recommended that the eggs should be turned through an angle of 45°. According to Phillips (1977) turning should commence 24 hours after setting and should be done twice daily, 8 am and 8 pm up to the 19th day of incubation. He noted that the third turning at the middle of the day though beneficial is not essential. Oluyemi and Roberts (1988) recommended that eggs should be turned not less than three times daily. They suggested an odd number of turning if turning is confined to the day time. If the turning time is even, the eggs will continue to rest on one particular side every night. Van Wageningen and Meinderts (1990) strongly recommended that the egg should be turned 3 times daily for the first 19 days of incubation after which turning is no longer necessary. They recommended that the egg should be turned 180° from the former position. Krueger (1977) reported that turning is most essential during the first week of incubation and becomes less important as embryonic development advances. The result of his research showed that at: (i) No turning during incubation, 29% hatched; (ii) Turning the first 7 days of incubation, 78% hatched; (iii) Turning the first 14 days of incubation, 95% hatched and turning the first 18 days of incubation, 92% hatched. The result showed that eggs must be turned at least the first seven days of incubation if respectable hatch is to be obtained.

2.2.2 Storage and other Factors that Affect Hatchability of Eggs.

The length of time and the environmental condition that an egg is stored before incubation has a tremendous effect on hatchability. It has been reported by several authors (Ademosun, 1968; Olomu, 1976, a b; Ogundipe and Oni, 1989), that hatchability of fertile eggs decline with the storage period. According to Strong (1979) the storage conditions on the breeder farm can affect hatchability. He noted the that the temperature and humidity in the egg holding room should be properly monitored and maintained within the optimum range until the eggs are picked up. North (1980) and Reynnells (1980) suggested 15.6°C - 18°C for egg storage for less than 7 days. For longer storage, they suggested that the temperature should be kept at 13°C -14°C while the relative humidity of 75 to 80% as essential to the production of quality eggs and chicks. If lower, the air moisture level would dehydrate the embryo. North (1980) reported that holding hatching eggs longer than 4 days prior to being placed in the incubator weakens the embryo and causes reduction in hatchability. However, Oluyemi and Roberts (1988) reported a reduction in hatchability by 4% per day for each extra storage day after the initial safe storage period of 6 days. They also noted a continuous cellular metabolism occurrence in the blastoderm during storage which gradually leads to blastodermal senescence and a moribund condition if the storage temperature

is more than 12.5°C whereas embryonic development is arrested at 12.5°C. Too low storage temperature causes the blastoderm to freeze. They suggested a relative humidity of 80% and above to prevent dehydration of eggs. Mather and Laughlin (1979) studied the interaction between the parental age and early embryonic development as affected by storage of hatching eggs. They found that storage of hatching eggs caused shrinkage of the blastoden. The amount of shrinkage decreased with parental age. They also found that the number of malformed embryos increased with storage time.

Harper (1980) gave the following physical factors as affecting hatchability, frequent collection of eggs, sanitation in production, cleaning methods, storage holding temperatures (13-14°C), humidity (70-75%), length of holding period - 1 to 2% hatchability loss daily for 7 day holding, packaging using non-permeable plastic bags for storing and fumigation or sanitizing eggs for disease control and possible pre-heating eggs with longer than 1 week holding time. Krueger and Fanguy (1979) discussed the following factors that affects hatchability, genetic background or type of hens; egg size or weight; age of eggs, breeder age, frequency of egg collection, egg processing and holding; the incubation temperature, humidity, inaccurate sensing equipment, ventilation and microbiological load. North (1980) also reported poor shell quality as affecting hatchability of chicken eggs. He noted that shell quality from young breeder

flocks is usually good, and hatches are high but as the bird continues on through her laying period, shell quality and shell thickness deteriorate and hatchability drops. He attributed this to the bird's inability to increase calcium deposition on the eggs to compensate for the increase in egg size during the latter part of the production period. Jones (1978) found that egg shell thickness is important to hatchability. He reported that the best result could be attained if the egg shells are within the range of 0.33 to 0.35 mm. He linked egg shell thickness with the breeders age that when the breeder are young, the egg shell thickness is excellent but as the breeder age, the shell thickness declines which contributes to the higher breakage and poor hatch from older stock. According to Waters (1979) infrequent gathering of eggs, besides hurting hatchability, causes broken eggs when eggs are being rolled against others and by toe punctures. He reported that trayingg too loose or tight causes losses during incubation. Reynnells (1980) also suggested gathering of incubating eggs more frequently. Gyles (1980) found that the larger the hatching egg, the longer the incubation period for male broiler chicks. He reported that late hatching male chicks also were heavier than early hatching chicks when both were weighed at the end of the hatch. He concluded that this may have been due to some dehydration that occured in the early hatching males. He also found that early hatching females chicks were heavier at 8 weeks of age than the late

hatching chicks and that older eggs have a longer incubation period.

2.3 Properties of Incubator Materials and Heat Transfer in Incubator

A thorough understanding of the thermal interaction between the egg and its environment is necessary for the approximation of heat stress, heat loss modes and the effectiveness of various environmental modifications (Canton **et-al**; 1983)

2.3.1 Thermal Properties of Wood for Incubator Design

The installation of proper insulation offers the greatest possibility for conserving energy in the incubator. Given the high cost of metal sheet and the lagging that would be needed to reduce heat loss, wood appears to be a preferred material for incubator design because of the insulating property and local availability.

Wood is an anisotropic material (material whose properties vary in different directions). Wood materials lose and gain moisture from the air depending on the variations in temperature and humidity which cause swelling and shrinkage of the wood.

The thermal conductivity varies from one wood to another. The small variations is primarily affected by the direction of the grains, moisture content, specific gravity and the wood composition in terms of early wood, late wood, checks and knotts. (Kazanas **et al.,** 1974; Clauser, 1975. According to

Everett (1970) the thermal conductivity of wood varies with temperature, porosity and the moisture content. The values of thermal conductivity is approximately equal in the radial and tangential directions but 2¼ - 2¾ times greater along the longitudinal axis. Kazanas **et. al.,** developed a formula for computing thermal conductivity of wood.

$$K = G[1.39 + C(M)] + 0.165 \quad --(2.1)$$

where

K = thermal conductivity (W/m°C)

G = Specific gravity at a given moisture content.

M = Moisture content in percentage

C = a figure based upon the moisture content, with an expressed value of 0.038 above 40% M and 0.028 below.

Table 2.2 gives the thermal properties of some wood materials as given by Everett (1970).

Table 2.2: The Thermal properties of some wood materials.

Materials	Bulk Density kg/m^3	Thermal Conductivity (K) w/m°C	Thermal restivity (1\k) m°C/W
Insulating fibreboard	240-400.5	0.053-0.065	18.9-15.4
medium hardboards	461-801	0.072-0.101	13.9-9.9
Standard and tempered hardboards	961(min)	0.125 & 0.180	8.0 & 5.7
Soft & plywoods	513	0.124	8.07
Particle boards	449-801	0.101-0.158	9.92-6.34
Plaster boards	961	0.16	6.25
Hard wood	769	0.16	6.25

Wood expands when heated and contracts when cooled though usually less than most engineering materials. Clauser (1975) and Kazanas **et. al.,** (1974) agreed that the thermal expansion differs in the longitudinal, radial and tangential directions. The thermal expansion along the grains are independent of density while it is density dependent across the grain. This should be considered in the design since heat is introduced to the incubator. If the material of construction is not of good thermal properties, there would be deterioration with time.

Presence of chemicals cause hydrolysis of the cellulose and attacks the lignin, producing swelling. Clauser (1975) reported the combination of moisture, air and micro-organisms as the major cause of wood decay. The rate of decay of wood varies greatly depending on the ambient conditions. The respiration of the eggs gives out carbondioxide which may

react with water to form reactive chemical with wood. However, woods with low decay resistance can be improved by a number of different preservative treatment. These include the use of creasote having offensive odour; petroleum oil fortified with chlorinated phenols that is odourless and non flamable; common water solution preservatives such as zinc chloride acid, copper and chromate and chromated copper arsenate; impregnation and compression and reconstitution of wood particles, chips and fibres.

Considering that incubator must conserve heat (that is, the material must be of low thermal conductivity) most of the available wood have limited width which may require joining and is thus a potential source for heat loss. A reconstituted wood material that is homogeneous such as plywood which is available in large dimensions, has equal strength in all directions and are moisture resistant than most wood can be used for incubator.

2.3.2 Heat Transfer in Incubators

There are two main mechanisms of fluid flow used in engineering analysis.

Laminar flow is flow in which the fluid moves in layers one layers gliding smoothly over an adjacent layer with only a molecular interchange of momentum (Streeter and Wyli, 1979). Heat transfer in a fluid with laminar motion along a surface of different temperature level is by molecular conduction

within the fluid as well as in the interface of the fluid and the surface.

Turbulent flow has very erratic motion of fluid particles with violent transverse interchange of momentum (Streeter and Wyhe, 1979). The fluid particles act as carriers of heat energy and transfer the energy by mixing with other particles of the fluid. An increase in the rate of mixing cause an increase in the rate of heat flow by convection (Kreith, 1976).

When a fluid flows along a surface irrespective of whether the flow is laminar or turbulent, the particles in the vicinity of the surface are slowed down by virtue of viscous forces. The fluid particles adjacent to the surface sticks to it and have zero velocity relative to the boundary. Other fluid particles that attempt to slide over them are retained as a result of an interaction between the faster and slower moving fluid which gives rise to shearing forces. When large quantities of heat is to be transferred rapidly, the boundary layer thickness is reduced as much as possible by increasing the velocity and/or the turbulence of the fluid.

In incubators, two general processes take place depending on the type of incubator. In forced convection, the fluid motion is caused by the external energy from a pump or fan applied to increase the turbulence of the heated air which invariably cause a better heat transfer. Forced heat convection is used in large cabinet incubator type.

On the other hand, free convection occur when the air inside the incubator chamber is at a lower temperature than that of the heat exchanger. Motion of air is set up as a result of density difference due to temperature variation inside the incubator. There is an upward flow of lighter heated air and downward flow of heavier air inside the incubator chamber. The free convective heat transfer coefficient is relatively low since the intensity of the mixing motion is generally less. The temperature difference increases the rate of heat transfer until a state of equilibrium is reached when the rate of heat generation is equal to the rate of heat dissipation (Kreith, 1976; Jacob and Hawkins, 1981).

Most table incubators available in the country now operate on the free convection principle. The heat transfer by free convection is influenced by the gravitational force due to thermal expansion, viscous drag and the thermal diffusion which are dependent on the gravitational acceleration g; the coefficient of thermal expansion B and the kinematic viscosity. These variables can be expressed in terms of dimensionless numbers given by Kreith (1976).

$$Nu = C\ (Gr.\ Pr)^{n} \qquad (2.2)$$

$$= \frac{hL}{K}$$

where Nu = Nusselt number
Gr = Grashof number
Pr = Prandtl number
K = Thermal conductivity w/m^0C
L = Characteristic length of the surface
c and n are constants depending on the physical configuration and nature of flow.

n = 0.25 for laminar natural convection
n = 0.33 for turbulent natural convection
h = Convective heat transfer coefficient $w/m^{2o}C$

The characteristic length L for different configuration is given in Table 2.3

Table 2.3: The characteristic length L for configuration

Vertical plates or pipes	L = Height
Horizontal plates	L = Length
Horizotal pipes	L = diameter
Sphere	L = 0.5 diameter
Rectangular block with horizontal length L_h and Vertical length L_v	$\frac{1}{L} = \frac{1}{L_v} + \frac{1}{L_h}$

The Nusselt number for planes and pipes are given as follows (ASHRAE,1977) for vertical or Horizontal planes, pipes, rectangular blocks and spheres

$$Nu = 0.56\ (Gr.\ Pr)^{0.25} \quad \text{----------2.3}$$

For $10^4 \leq (Gr.\ Pr) \leq 10^8$ Laminar range

$$Nu = 0.13\ (Gr.\ Pr)^{0.33} \quad \text{---------- (2.4)}$$

For $10^8 \leq (Gr.\ Pr) \leq 10^{12}$ Turbulent range

The value of the heat transfer coefficient for laminar

free convection from an isothermal vertical cylinder at a distance x from the leading edge as given by Kreith (1976) is

$$h_{cx} = 0.41 \frac{k}{x}(Pr.\ Gr)^{1/4} \quad \text{---------- (2.5)}$$

Since the incubator is an enclosed chamber, the air at constant pressure expands when heated. The air layer adjacent to the walls of the exchanger expands, becomes lighter and then rises to be replaced by cooler air.

The empirical formula for calculating the free convective heat transfer in such an enclosed air space between vertical walls are presented by Kreith (1976) as

$$Nu = 0.18\ Gr^{1/4} \left(\frac{L}{\delta}\right)^{-1/9} \quad \text{---------- (2.6)}$$

For $2,000 < Gr < 20,000$

$$Nu = 0.065\ Gr^{1/3} \left(\frac{L}{\delta}\right)^{-1/9} \quad \text{---------- (2.7)}$$

For $20,000 < Gr < 11 \times 10^6$

Where
δ = thickness of the air space
L = height of the air space
Gr= Grashof number.

For Grashof number below 2,000, the heat transfer is essentially all conduction, so the Nusselt number for the region is equal to unity (Kreith, 1976).

2.4 Heat Exchange in Incubators.

A heat exchanger is a device in which heat is transferred from one fluid to another fluid which are

physically separated (Kays and London, 1984). The heat is transferred from the warm air to the pipe by conduction and convection through the air film, then through the pipe wall by molecular conduction and finally to the cold air inside the incubator.

In an incubator, the adjacent particles close to the exchanger get heated by conduction and moves to a region of lower temperature where they mix and transfer some part of the energy to the other fluid particles. This is replaced by colder air which is more dense. The process continues until a state of equilibrium is reached when the temperature inside the incubator is uniform.

Generally, heat exchange between the exchanger and the air (medium) may be carried out in various ways: (i) by allowing the air streams transverse the exchanger only once (Single pass); (ii) by allowing both fluid flow in the same direction as in the parallel flow type. Here the final temperature of the colder fluid can never reach the exit temperature of the hotter fluid (Kreith, 1976); (iii) by allowing the fluids to move in the opposite directions as in the counter flow type. The final temperature of the colder fluid may exceed the outlet temperature of the hotter fluid as a favorable temperature gradient exists all along the heat exchanger. Also less surface area is required for a given rate of heat flow than in the parallel flow type (Kreith, 1981); (iv) by allowing the fluid flow in perpendicular

directions as in cross flow type. Of all the four types of heat exchanger described, the most common in table incubators are the single pass and the counter flow type.

Giese and Ibrahim (1950) reported theoretically and experimentally that the counterflow system results in greater heat transfer than the parallel flow. In the parallel flow system, there is a maximum temperature difference between the incoming and exhaust air at the point of entrance but a minimum difference at the point of discharge, while in the counter flow system, the temperature difference is more nearly constant. According to Giese and Bond (1952) the greatest obstacle to the use of heat exchangers in animal shelters is the ordinarily low temperature differential existing between the warm (exhaust) air and the cold (incoming) air in the exchanger. They noted that the required heat transfer must be accomplished by a larger heat transfer surface or a very high fluid velocity in the exchanger. They recommended that since the fluid velocity affects the operational cost in overcoming fluid friction, an exchanger with a large surface area would seem to be the most economical. Giese and Ibrahim (1950) reported that decreasing the diameters of heat exchanger pipes results in more surface area than for larger diameter pipes for the same velocity of flow. On the other hand, they indicated that if the surface and number of inlets and outlets are increased, more power would be needed to move the air through the pipes. They concluded that for the same number of

pipes of different diameters, the smaller the diameter, the higher the velocity and the higher the velocity , the higher is the heat gained and the power consumed to move the air.

Walkers **et al,** (1986) concluded that the overall heat transfer coefficient is the best measure of an agricultural heat exchanger's performance. They reported that if it is necessary to use effectiveness values to denote a heat exchanger's performance, they recommended that enthalpy effectiveness rather than temperature effectiveness be used for any application where condensation may occur on the heat exchanger surface. According to Leinhard (1981) when the temperature of either fluid in a heat exchanger stays constant, the problem of analysing the heat exchanger is simplified and this makes the configuration of the heat exchanger to be irrelevant.

The total heat transfer through the heat exchanger can be calculated from the equation

$$Q = UA \Delta T_{lm} \quad \text{----------} \qquad (2.9)$$

where

Q = the total heat transfer

U = overall heat transfer coefficient $W/_{m}{}^{2o}C$

A = effective heat transfer surface area of the exchanger

ΔT_{lm} = logarithmic mean temperature difference °C

The temperature of the fluids in a heat exchanger is generally not constant. It varies from point to point as the heat flows from the hot region to the colder region. Thus the

use of the logarithmic mean temperature difference can be calculated from

$$Tim = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{Ln \left\{ \frac{T_{hi} - T_{co}}{T_{ho} - T_{ci}} \right\}} \quad \text{----------} \quad (2.10)$$

where

T_{lm} - logarithmic mean Temperature difference °C

T_{hi} = average temperature of air entering the hot side of exchanger °C

T_{co} = temperature of air leaving the incubator °C

T_{ci} = temperature of air entering the incubator °C

T_{ho} = Temperature of air leaving the exchanger °C

The heat exchanger effectiveness which is the ratio of actual heat transfer to the potential heat transfer can be calculated using the enthalpy effectiveness as follows:

$$E_e = \frac{q_{act}}{q_{max}} = \frac{M_c \; C_p \; (T_{co} - T_{ci})}{M_h \; (h_{hi} - h_s)} \quad --- \quad (2.11)$$

where

E_e = enthalpy effectiveness of the heat exchanger

q_{act} = actual or useful heat transfer KW

M_c = mass flow rate of air in the incubator measured in the transfer duct (kg/s)

M_h = total mass flow rate of air in the hot side of the exchanger, measured at the room outlet. (kg/s)

h_{hi} = average enthalpy of the air entering the hot side of the exchanger kJ/Kg

h_s = enthalpy of saturated air at T_{ci} KJ/Kg

2.5 Temperature Control in Incubator

Control in an incubator serves to maintain the design conditions, reduce the amount of human labour required to operate and maintain the system. It reduces cost and the chances of errors, minimise energy use and cost and keep the operation of the equipment at safe level thereby preventing damage to property and people.

Various types of control actions have been developed which have been adapted for use in incubator. Pita (1981) and Schneider (1981) described the various control actions available as i) the two position action which can be either fully closed or fully opened (ii) Timed two position control with a heat anticipation device to reduce the operating differential and improve the sensitivity (iii). Floating action control with three positions instead of two. The third position is a neutral or dead band. (iv) proportional action which is most common type of control in incubator design. The control action varies in proportion to the amount of change in temperature inside the incubator chamber.

There are some temperature sensing devices that are mostly used. The bimetal element uses the difference in the coefficient of thermal expansion of two dissimilar metal that are bonded together for the control action. The radius of curvature r for the expanding bimetal element can be calculated from the formula given by Eskin and Fritze (1940) quoted in Holman (1966) and Doebelin (1966) as

$$r = \frac{t\,[\,3(1+m)^2 + (1+mn)(m^2 + 1\backslash mn)\,]}{6(\alpha_2 - \alpha_1)(T-T_o)(1+m)^2} \qquad \text{-------- (2.12)}$$

Where

t = combined thickness of the bonded strip

m = ratio of thickness of low expansion material to high expansion material.

n = ratio of moduli of low expansion to high expansion metals.

α_1 = Lower coefficient of expansion

α_2 = Higher coefficient of expansion

T = Temperature °C

T_o = Initial bonding temperature °C

The pressure developed by a fluid can also be used for control. A volatile fluid can be contained in a closed flexible vessel which expand or contract with increase or decrease in temperature. The relationship between the temperature and pressure is predictable and is fluid dependent. An empirical relationship between temperature and pressure quoted by O'Higgins (1966) is

$$\log_{10}P = \frac{-0.05223a + b}{T} \qquad \text{----------(2.13)}$$

Where

P = Absolute pressure, mm Hg
T = Absolute temperature, °K
a and b are constant.

The resistance of a wire varies as the temperature changes. This action can be calibrated and utilized to control the temperature inside the incubator.

CHAPTER 3

MATERIALS AND METHODS

3.1 Design Considerations

The incubator was designed with the following conditions taken to considerations.

i. Environmental - the following environmental conditions are necessary for the successful operation of the incubator.

Temperature - the recommended dry bulb temperature of 37.2 - 39.40°C for 3 weeks to be uniformly distributed inside the incubator.

Relative humidity should be between 50 - 60% inside the incubator. This will prevent the drying of the egg content and the drowning of chicks due to low and high relative humidity respectively. Placement of watering troughs to condition the air inside the incubator is required.

Ventilation - adequate ventilation is required to remove moisture, obnoxions gases, maintain satisfactory temperature and relative humidity. Provision of large air inlet and delayed airflow inside the incubator is necessary.

ii) Cost - Phywood was used to achieve better insulation at a reduce cost, to make the incubator affordable to the majority of farmers.

iii) Durability - The selection of maternals for the construction was made to enable long term usage and easy cleaning after incubation.

iv) Heat exchanger design - This was made to distribute heat uniformly inside the incubator. The exposed portion to be insulated to reduce heat loss.

v) Heating source - The availability of fuel and the ease of operation is very important.

vi) Control - High sensitivity is required to control the temperature inside the incubator.

3.2 The Incubator Design

A 60 eggs, low cost incubator was designed and constructed. The design is the hot air type, kerosine fired, constructed from 3/4"(15mm) plywood to reduce the initial cost. The following advantages of plywood enhanced its choice:

(i) heat insulating characteristics, an equalized strength along the length and width of the panel;

(ii) greater resistance to splitting and checking and it is dimensionally more stable with changes in moisture content and above all;

(iii) localy availability.

The incubator is a rectangular box 450 mm by 380 mm by 430 mm dimensions with two 410mm by 310mm egg trays. The base of the trays are constructed with wire nets to permit the

passage of the conditioned air and for easy cleaning after hatching. The egg trays slide on railings made of wood 25mm by 20mm across the width of the incubator. This permits easy removal of the trays for turning operation. The orthographic projections of the incubator is in the Appendix.

Two rectangular slots 200mm by 50mm were made on the left and right wall of the incubator for ventilation. The one at the left 20mm from the base of the incubator serves as inlet while the right side of the incubator 30mm from the top serves as outlet. The intlet and outlet have variable gate to regulate the ventilation rate.

Two water troughs of 750ml capacity each were constructed from galvanized iron sheet metal and placed at the base of the incubator.

The source of heat is the kerosine stove placed 20 mm from the incubator outside the incubator. It is a six (6) wick fed blue flame kerosine stove. The choice of the stove was made on the basis that it can utilize kerosine effectively. It has also a fairly long economic life, low maintenance cost and it requires minimal attendance while in operation. The stove was purchased while the tank was constructed to increase the capacity.

The heating unit of the incubator consist of the **heat exchanger**, (a device to transfer heat from one fluid to another which are physically separated), the stove and the vertical conduit pipe on the stove.

The vertical conduit pipe on the stove provides a means of conveying the hot air from the stove to the heat exchanger. It is a 93mm diameter open ended pipe constructed from gage 16 sheet metal insulated to minimise the heat loss. The height of the conduit pipe is 110mm. This is embedded inside a 150mm diameter galvanised metal sheet of height 130mm to reduce heat loss.

The heat exchanger, a U shell and tube form of exchanger was constructed from a 40 mm diameter black pipe. The exchanger was positioned horizontally 20mm from the base of the incubator. The stove and the open end of the exchanger is located at the back of the incubator.

The kerosine fuel tank of 2 litres capacity was constructed from gage 16 iron sheet metal and painted to reduce corrosion.

3.3 The Operational Principles of the Incubator.

The incubator operates on the principles of natural convective heat transfer with heating from below. The sensible heat to heat the incoming ventilating air and remove moisture is supplied by the egg and the heat exchanger.

The exhaust gas from the stove is transported via the conduit pipe to the heat exchanger. The gases transverse the length of the U tube exchanger losing its heat to the pipe wall. The heat flow by conduction from the conducting interface (pipe wall) to the air inside the incubator in the

neigbourhood of the pipe transfering energy to the particles to increase their temperature and internal energy. The rise in temperature in the particles near the exchanger induces a density variation in the air inside the incubator creating a buoyancy driven flow. The energized air particles move to regions of lower temperature inside the incubator, mix with other air particles and transfer part of their energy also. The colder air in the incubator replaces the displaced hot air and the buoyancy induced flow current continues.

Condensed water vapour is undesirable because it causes the decomposition of incubator's components and thereby reduces the insulating capacity. Hence a major function of ventilation in the incubator is the circulation of air of such temperature and relative humidity as to provide satisfactory environmental conditions for the embryo's development and remove moisture produced, and other gases within the incubator. The uniformity of fresh air distribution inside the incubator is dependent upon the location and the cross-sectional area of the openings. The amount of air required is dependent on the temperature and humidity of the incoming and exhaust air and upon the heat and moisture produced by the eggs, hence an adjustable inlet and outlet was provided.

3.4 Preliminary Study of Temperature Control in the Kerosine Fired Incubator

Various attempts were made to develop a temperature controller using locally available materials, which can suitably and effectively sense the temperature inside the incubator and actuate the damper on the conduit pipe to an open or closed position. When the damper is in closed position, (Fig 3.1a) hot exhaust gases from the stove, through a path of least resistance will pass through the heat exchanger. In the open position, (fig. 3.1b), because of the high resistance of the heat exchanger path, the hot air will escape without passing through the exchanger. At other positions of the damper, the hot gases will be shared between the two paths. The temperature controller consists of two main parts. The sensing unit and the output mechanism.

The sensing unit is located 50 mm from the top of the incubator and 225 mm from the sides where the condition inside can be favourably measured. The sensing unit transfers the signal to the output mechanism which actuates the damper.

Various methods were explored to sense the low temperature in the kerosine fired incubator. These include

I) Bimetallic strips: Bimetals of various thicknesses were tested. They could not be used because of their low sensitivity in the temperature range 36°C - 39.4°C to be controlled.

II) Thermistors: Materials which exhibit a change in the

electrical resistance with change in temperature were also explored. Though good in principle, it could not be applied because the maximum operative temperature of the

locally available thermistor was 25°C which is below the operational temperature of 36°C - 39.4°C the incubator.

III) Diaphramic control: knowing that the volumetric expansion of liquid gives an almost linear response to temperature changes and based on the availability of chemicals, experiments were conducted on the feasibility of using Dimethyl ether and Acetone. Various dimensions of aluminum containers of width 5cm and depth 8cm; width 3cm and depth 5cm were attempted to determine the effect of the container shape size and the volume of liquid content on the pressure developed. Though the experiment was successful, the solubility index of the organic solvents were very close to that of available adhesives (Aradite and super glue). The solvents thus dissolved the adhesives, causing leakage of the liquid. Therefore the air-tight condition that is necessary for the controller to operate could not be obtained. The leakage of the organic solvents is highly dangerous as they are highly flamable and, besides, the odour can have adverse effect on the development of the eggs being incubated.

Following the initial success of the diaphragm control, efforts were directed at getting a perfect seal. Also other flexible materials were tested. Materials like ballons, condom and collapsible containers. There was problem getting a perfect seal for a long time without leakage.

IV) Syringe: The concept of expansion of liquid to displace the syringe piston was also considered. So the piston displacement could be used for output mechanism of opening or closing the damper. But the organic solvent reacted with the plastic syringe making it very stiff and difficult to operate.

V) Electromechanical: A thermostat which can be set at a predetermined temperature level was connected to an electro-magnet. When the temperature insive the incubator is higher than the incubator optimum operating temperature, current was allowed to flow through the electromagnet causing a magnetic flux to be created which is used to open or close the damper.

3.4.1 Description of the Developed Temperature Controller.

It consists of a solenoid of 1,500 turns made from gage 30 (0.315mm) copper wire. There is a rectangular shaped hole of dimension 68.8mm by 17.5mm by 14.6mm at the center to permit a permanent magnet bar to pass through.

The coil was connected to the thermostat and the battery. When current flows, with the temperature inside the incubator greater than the set temperature, magnetic field is induced in the coil which repels the magnetic field of the permanent magnetic bar. This repulsive force causes the motion of the magnet. The damper which opens or close the heat vent is connected to the magnet. The downward movement of the magnet

A - STOVE
B - VERTICAL CONDUIT PIPE
C - DAMPER
D - HEAT EXCHANGER
E - WET BULB THERMOMETER
F - DRY BULB THERMOMETER

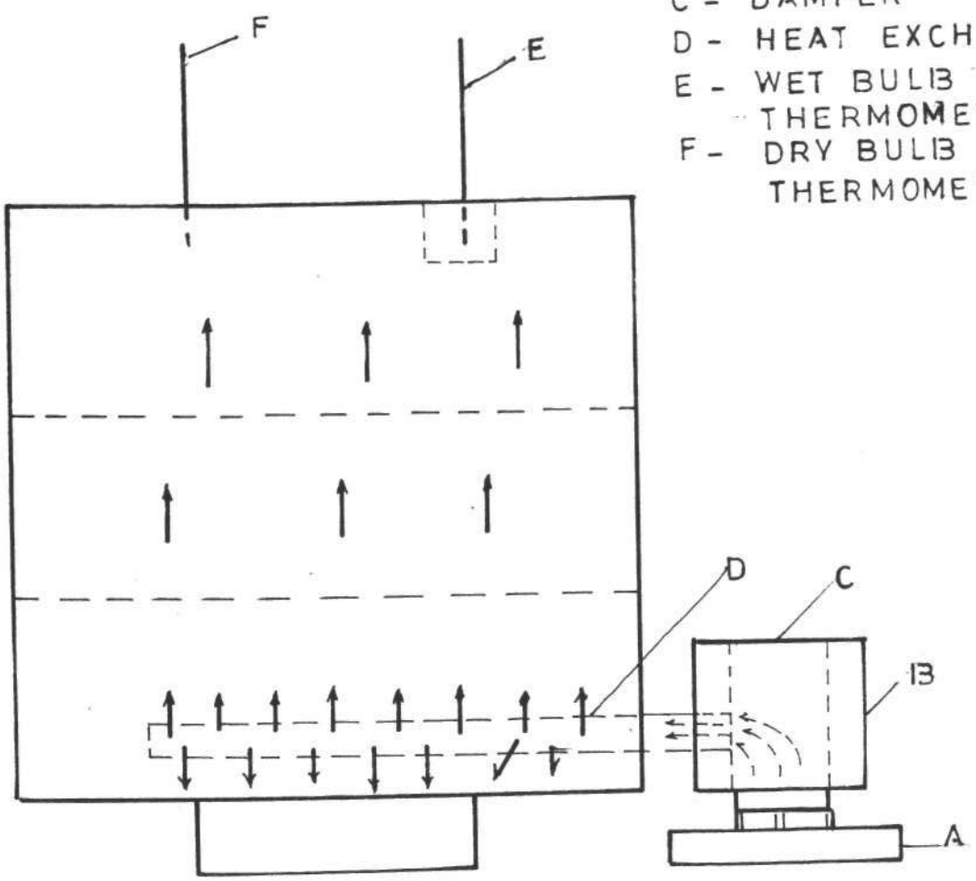


FIG.31.A-SCHEMATIC OF THE PATH OF AIR FLOW IN THE INCUBATOR WITH DAMPER CLOSED

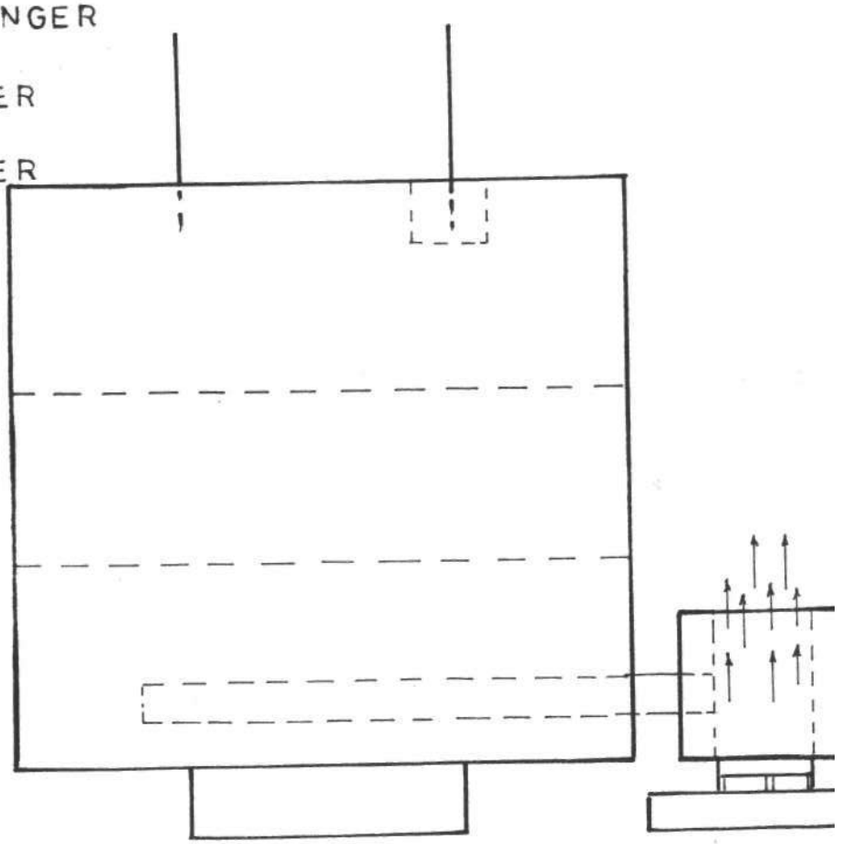


FIG.31.B, SCHEMATIC OF THE PATH OF AIR FLOW IN THE INCUBATOR WITH DAMPER OPENED

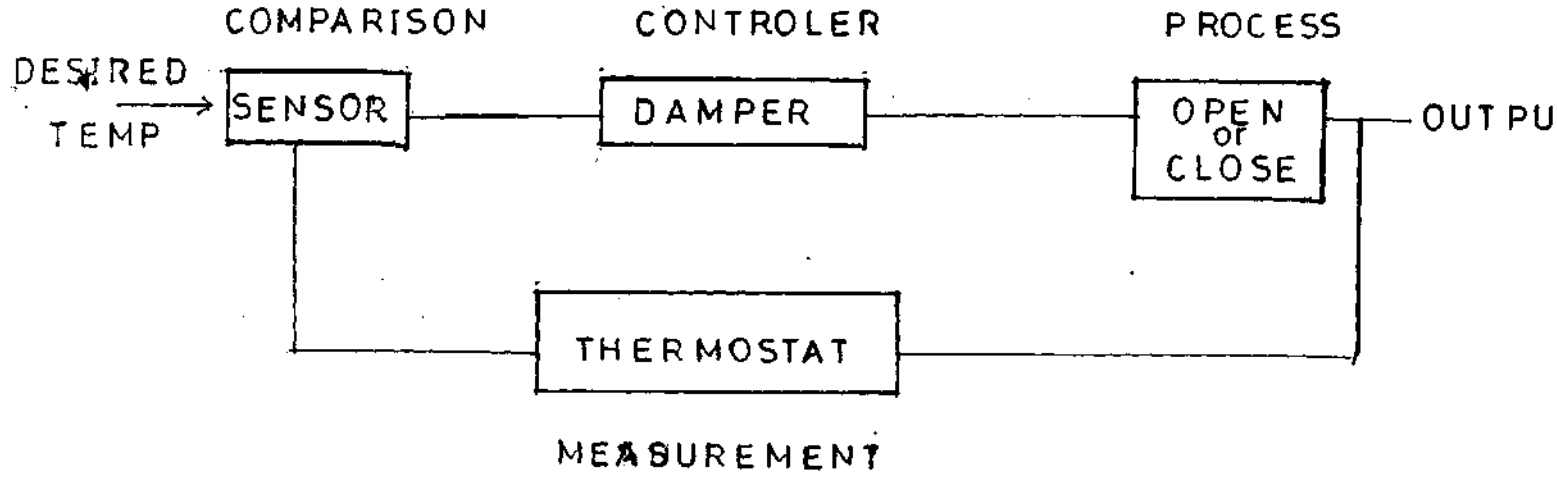
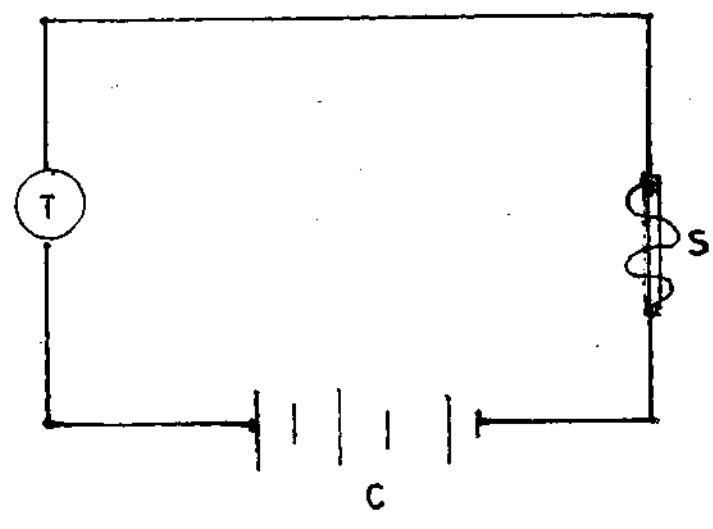


FIG. 3.2. SCHEMATIC OF THE CONTROL MECHANISM



KEY

T- THERMOSTAT

S- SOLENOID

C- ACCUMULATO

FIG 2.3 CIRCUIT DIAGRAM OF THE CONTROL MECHANISM

causes the damper to be opened. When the temperature inside the incubator decreased, the thermostat control cuts off the flow of current and the damper closes.

Fig 3.2 Show the schematic diagram of the temperature controller while plate 1 gives the assembly of the controller components. If the direction of the current is reversed, the force on the magnetic bar also changes.

The current flowing through the solenoid is obtained from the ohms law relationship.

$$V = IR.$$

A 12 V car battery was used while the resistance across the terminals of the coil was 32 ohms.

$$I = \frac{12\ V}{32\ V} = 0.38\ A.$$

3.4.2 Calibration of the Temperature Controller.

Six equal subdivisions were made on the thermostat regulator. Position 1 tallied with 30° while position 6 tallied with 180°. Each interval has 30° increment.

The incubator components were assembled and allowed to function. The regulator was set at each position while the temperature at which the damper opens was noted and recorded. There are two replications for each position. The readings taken by increasing the knob position and the replication while decreasing the knob position. The readings were

analysed using the regression analysis to obtain the calibration curve of thermometer reading as a function of position.

3.5 Cost Estimation

The production cost of the kerosine fire incubator is given in table 3.4:

Table 3.4 : Bill of Quantities for the Incubator

S/NO	MATERIAL	QUANTITY USED	UNIT COST ₦	TOTAL COST ₦
1.	3/4" plywood	4" by 4"	500.00	500.00
2.	1/2" block pipe	1/4 length	82.50	82.50
3.	Nails (Assorted)		60.00	60.00
4.	Mosquito nets		250.00	250.00
5.	Stove	1	350.00	350.00
6.	Hinges	2	10	20.00
7.	Gage 16 sheet metal	50cm by 50cm	30.00	30.00
8.	Paint (black)	1	50.00	50.00
9.	Foam (insulation)		10.00	10.00
10.	Glue		35.00	35.00
11.	Welding Electrode	3	40.00	120.00
12.	Labour			300.00
13.	Battery (12V)			2,500.00
14.	Magnet	100		100.00
15.	Copper coils (guage 30)	300		300.00
	TOTAL			4707.50

The production cost for the kerosine fired incubator as at April 1995 is four-thousand seven hundred and seven Naira fifty kobo only.

3.6 Egg Hatching Experiments

Hatchable eggs crossbred from Rhode Island Red (RIR) and Rhode Island White (RIW) were obtained from NAPRI hatchery

unit, Shika, ABU, Zaria.

The first hatching experiment was conducted between 3/2/95 to 24/2/95. Thirty (30) hatchable eggs were set inside the incubator. They were identified at the pointed end. All the eggs were cross marked on the side.

The Second Experiment was carried out between 16/3/95 - 6/4/95.

Thirty (30) hatchable eggs were set inside the incubator. The eggs were indentified at the pointed end. All the eggs cross-marked on the side.

The Third Experiment was based on the experience gained from the first and second hatching experiments. The third experiment was staggered. It was carried out between 8/7/95 and 2/8/95. The eggs were laid on 6/7/95 and bought on 7/7/95.

Twenty Seven hatchable eggs were identified at the pointed end. All the eggs were cross marked on the side. The eggs were divided into three groups of 9 eggs per group. Group 1 were set into the incubator on 8/7/95, Group 2 on 10/7/95 and finally group 3 on 12/7/95.

The thermometers were placed in positions to read both the wet bulb and dry bulb temperatures of the incubator and room condition respectively. The temperature readings were taken three times a day.

Four instead of the six wicks of the stove were used to reduce the amount of heat produced. The kerosine tank was

initially filled and the wicks were properly trimmed. The kerosine level was checked every day.

Turning of the eggs was at least three times daily according to established procedure. The eggs were turned at 6 am, 12 noon and 6 pm.

Incubated eggs were candled at 7,14,18, days of incubation to determine whether the egg contains a live embryo, or is infertile. For the purpose of candling, the room was darkened so that the only light comes through the hole of the candler. The egg is held in front of the light with the broad end at a 45° angle to the light and turned slowly from left to right to observe the following:

I) Live Embryo: the fertile egg incubated for 7 days has an embryo which resembles a large red spider due to the radiating blood vessels. On the 18th day, the living embryo will show a larger section containing the embryo and a smaller section which is clear containing the air space.

II) Dead embryo: On the 18th day, the fertile egg is depicted by opaqueness and lack of air space.

III) Infertile egg: the egg is clear except for a yolk shadow.

Plate 2 shows the incubator with the hatchable eggs.

After testing the incubated eggs, the live embryos were returned back to the incubator and the dead and infertile eggs were opened up to examine the contents. The information obtained were recorded.

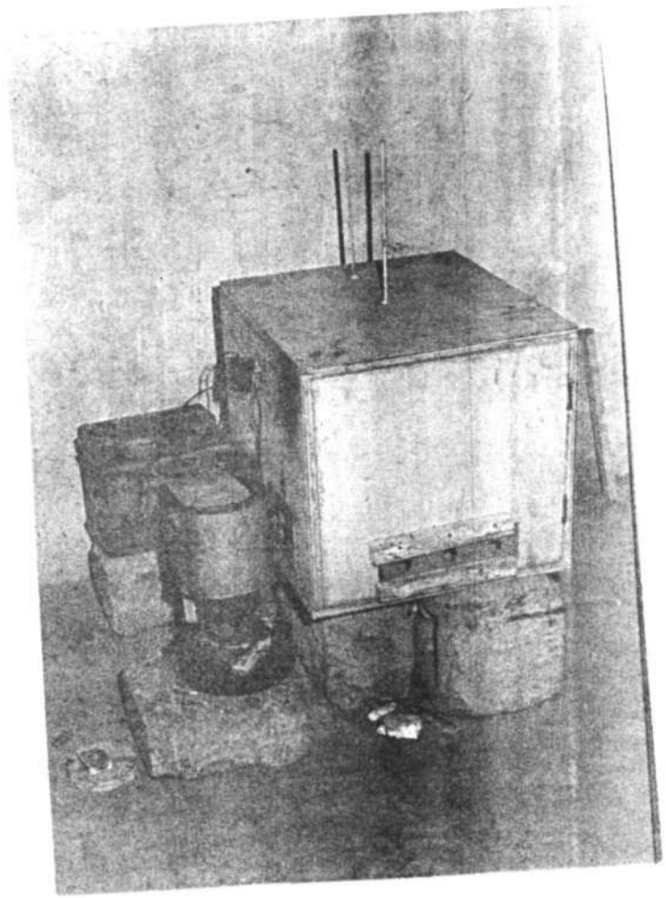


PLATE 3:1 The Assembly of the components of the Developed con

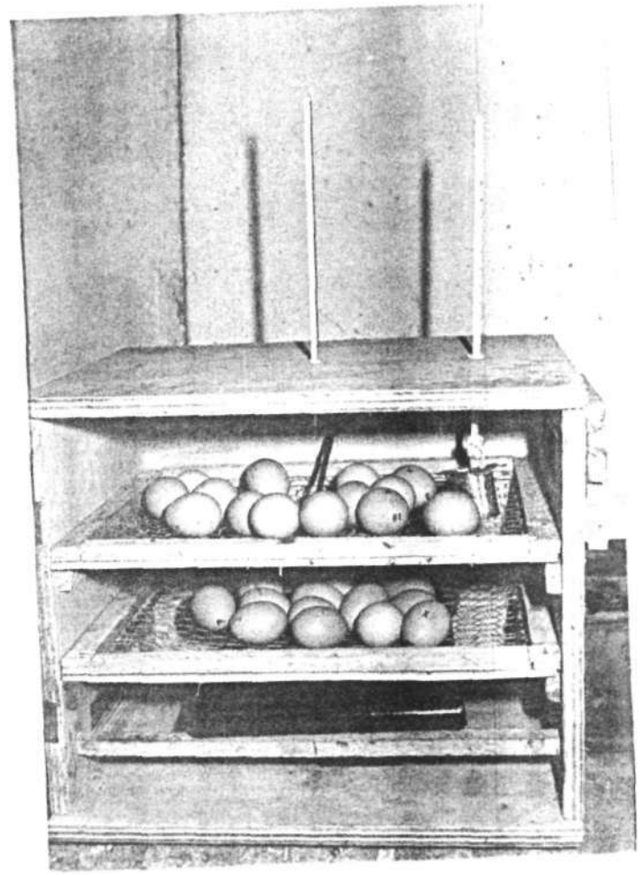


Plate 2:2 The Incubator with the Hatchable Eggs

The incubator was not opened after the 18th day of incubation neither ware the eggs turned, since the embryos were moved into the hatching position. Four days prior to hatching, sack layers were laid on the wire platform to reduced the possibility of injury to the navel of the hatching chicks and also help to keep the incubator clean.

The chicks were allowed to dry off before removing them from the incubator. The following information were recorded on the incubation data sheet.

a) Date of setting.

b) Number of eggs that are fertile.

c) Daily record of room and incubator temperatures.

d) Number of eggs that are fertile.

e) Number of fertile eggs that hatched

f) Percentage of eggs that hatched from all the egg set.

$$\text{This is the percentage fertility} = \frac{\text{Number of fertile eggs}}{\text{Total number of eggs set}} \times \frac{100}{1}$$

g) Percentage of eggs that hatched from fertile eggs which is the percentage hatchability of fertile eggs

$$= \frac{\text{Number of fertile chicks}}{\text{Total number of fertile egg set}} \times \frac{100}{1}$$

H) Hatchability losses were determined by breaking the incubated eggs.

CHAPTER 4

RESULTS AND DISCUSSIONS.

4.1 Calibration of the Temperature Controller.

A plot of the readings of the temperature inside the incubator at different thermostat knob positions is presented in fig 4.4.

A linear regression analysis on the data to obtain the best one variable model relating the temperature inside the incubator to the different positions resulted in the regression equation.

$$T = 27.99 + 6.54\ x$$

where T = Temperature inside the incubator

x = Knob positions

A Regression coefficient (R^2) of 99.3% was obtained which shows a high positive relationship between the incubator temperature and the knob position.

The analysis shows that the temperature inside the incubator would increase by the increase in the distance of the knob from zero. This implies the temperature required to open the damper would increase with increase in knob position.

Since the temperature inside the incubator must be less than 40°C for a good hatching of eggs, the knob position of the thermostat was therefore set at position very close to mark 2 throughout the period of incubation.

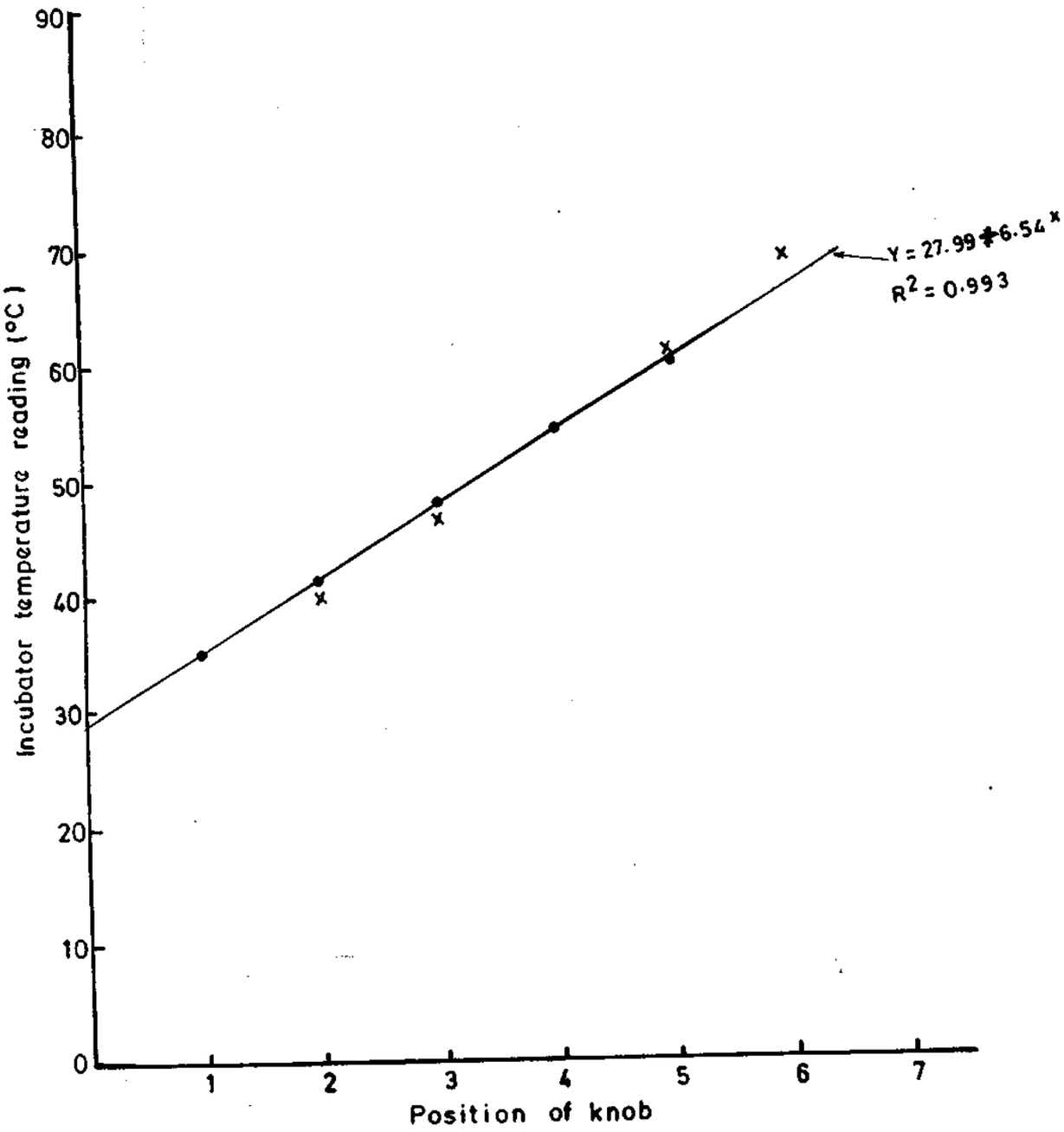


FIG. 4.4: CALIBRATION OF INCUBATION TEMPERATURE AGAINST POSITION OF THE KNOB.

4.2 Daily Variations of Temperatures and Relative Humidity.

A record of the observations of the dry and wet bulb temperatures inside the incubator and the room made during the incubation period is presented in Appendix B. Table 4.5 and 4.6 presents the mean Temperature in the Room and Incubator during the hatching experiments.

Table 4-5: Mean Temperatures in the Room

			D.B. ^{o}C			W.B. ^{o}C		
			6am	12noon	6pm	6am	12noon	6pm
I		Mean	23.4	25.2	29.0	18.3	19.1	20
		Cv	3.55	4.88	5.65	6.02	4.88	4.26
II		Mean	28.8	29.9	30.7	21.2	22.6	23.5
		Cv	2.00	2.73	3.16	3.46	3.47	3.57
III	a	Mean	25.6	28.0	28.3	22.9	24.1	24.4
		Cv	1.95	4.01	3.64	2.86	3.60	4.13
	b	Mean	25.6	27.9	28.3	22.7	24.0	24.2
		Cv	1.91	4.20	3.82	2.78	3.02	3.10
	c	Mean	25.6	27.8	28.1	22.8	24.1	24.2
		Cv	2.00	4.39	4.02	2.59	2.72	3.0

Table 4-6: Mean Temperatures in the Incubator

			D.B. ^{o}C			W.B. ^{o}C		
			6am	12noon	6pm	6am	12noon	6pm
I		Mean	35.5	36.6	37.4	26.6	28.5	28.9
		Cv	1.44	1.40	1.95	2.73	3.02	2.22
II		Mean	35.6	36.3	36.9	26.1	26.8	27.4
		Cv	2.24	1.74	1.65	2.45	2.48	1.80
III		Mean	34.3	36.5	37.5	25.6	27.6	28.3
		Cv	4.17	3.07	0.48	3.83	4.20	3.65
		Mean	34.5	36.5	37.6	25.7	27.8	28.6
		Cv	4.27	3.01	1.94	4.05	4.00	3.19
		Mean	34.4	36.5	37.7	25.8	27.8	28.7
		Cv	3.96	2.63	1.91	3.96		

i. Hatching Experiment 1

Fig 4.5 gives the plot of variation of the dry bulb temperature and the relative humidity of the incubator and the room with the days of incubation.

The highest average daily dry bulb temperature value obtained was 37°C while the lowest dry bulb temperature was 36°C.

The highest dry bulb temperature value inside the room during the period of incubation was 27°C and the lowest value was 23°C.

Also the highest relative humidity inside the incubator was 60% while the lowest value obtained was 46%.

ii. Hatching Experiment 2

Fig 4.6 show the plot of the variations in the dry bulb temperature and relative humidity inside the incubator and the room during the period of incubation.

The highest incubator average daily dry bulb temperature value was 37°C while the lowest value was 36°C. The highest average dry bulb temperature during the period incubation was 31°C while the lowest was 29°C.

The relative humidity has its highest value of 60% while the lowest values was 45%

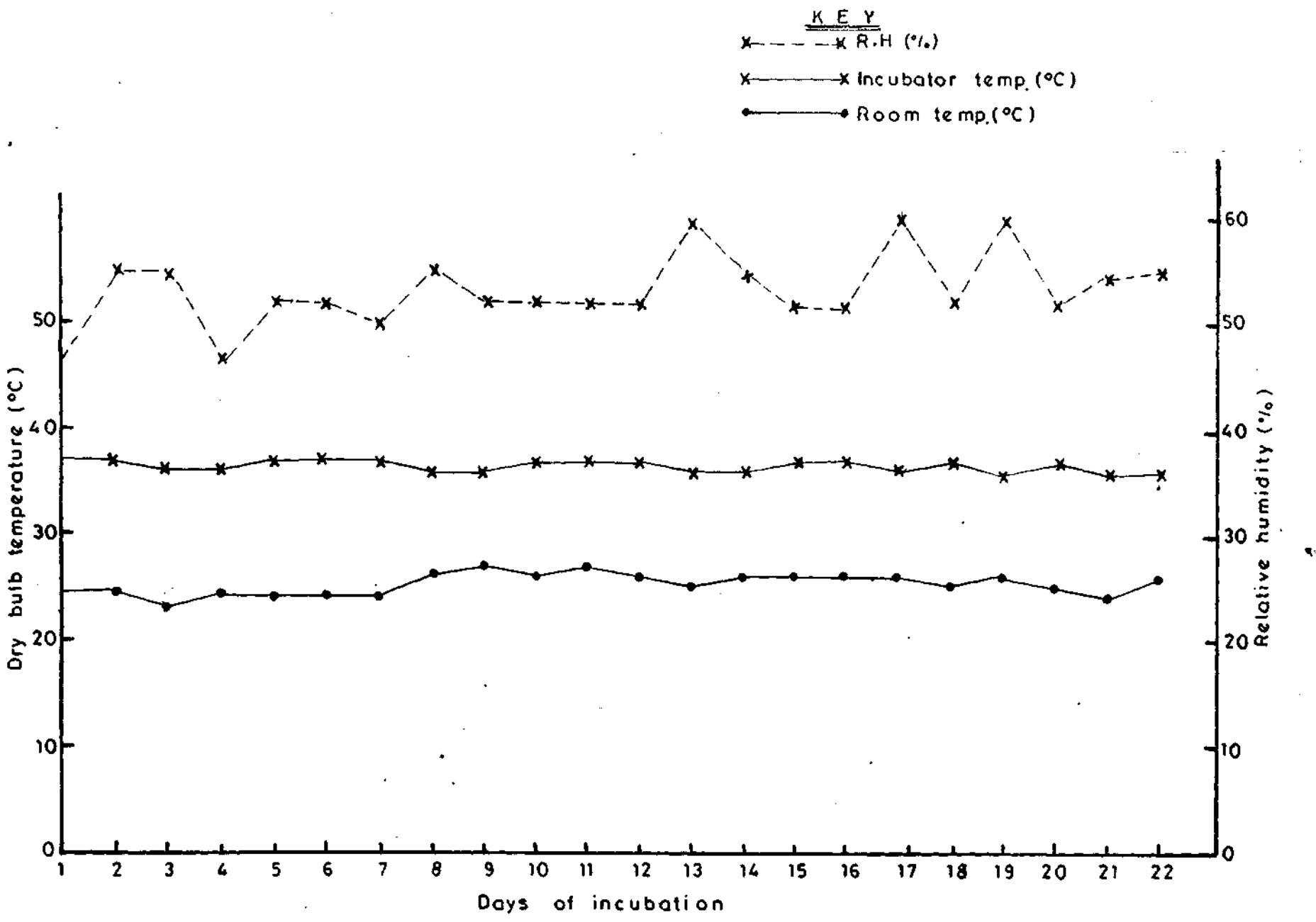


FIG. 4.5: VARIATION OF DRY BULB TEMPERATURES AND RELATIVE HUMIDITY WITH THE DAYS OF INCUBATION

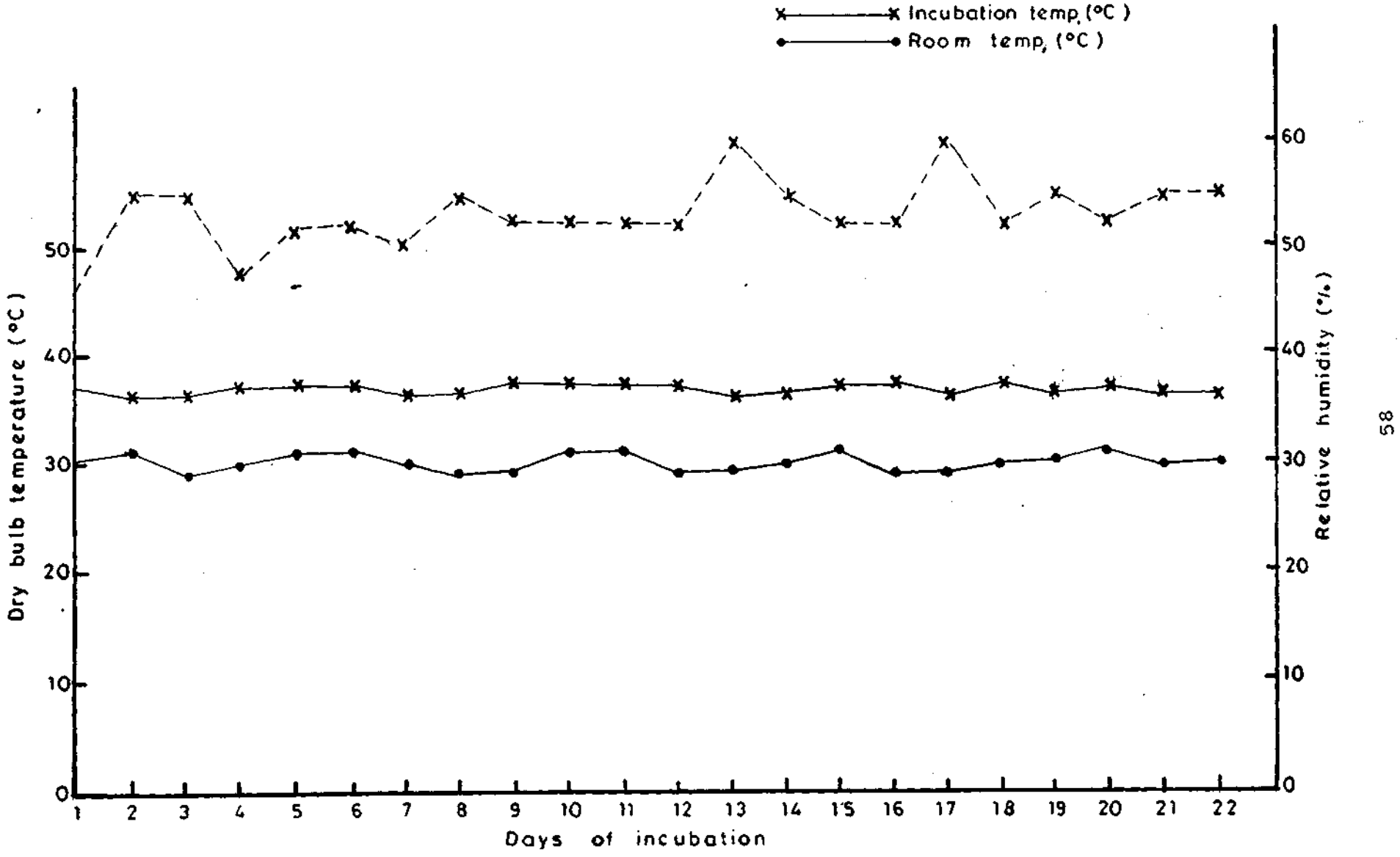


FIG.4.6 : VARIATIONS OF THE DRY BULB TEMPERATURE AND RELATIVE HUMIDITY WITH THE DAYS OF INCUBATION

HATCHING EXPERIMENT
GROUP 1

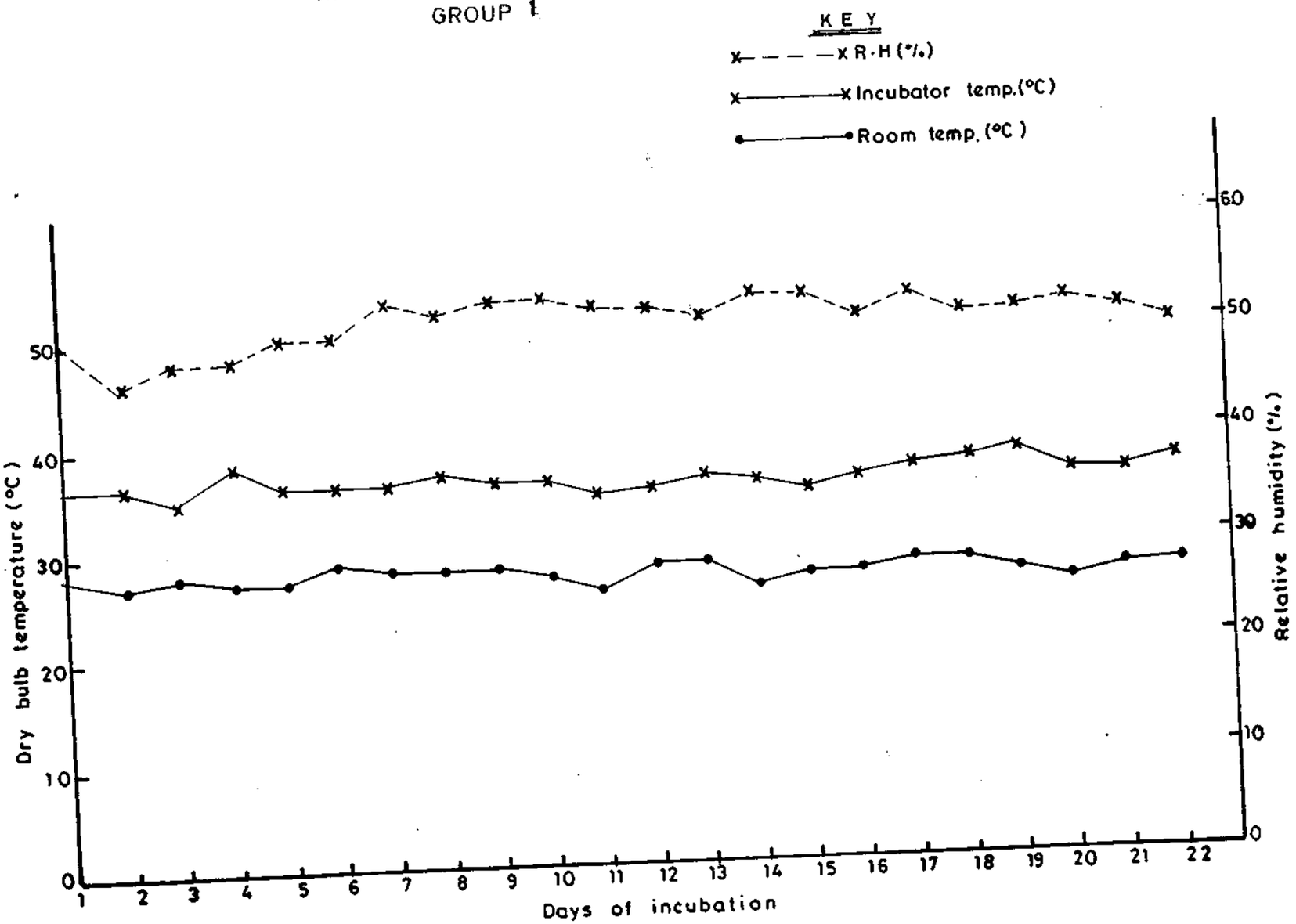


FIG. 4.7(a): VARIATION OF THE DRY BULB TEMPERATURES AND RELATIVE HUMIDITY WITH THE DAYS OF INCUBATION

GROUP II

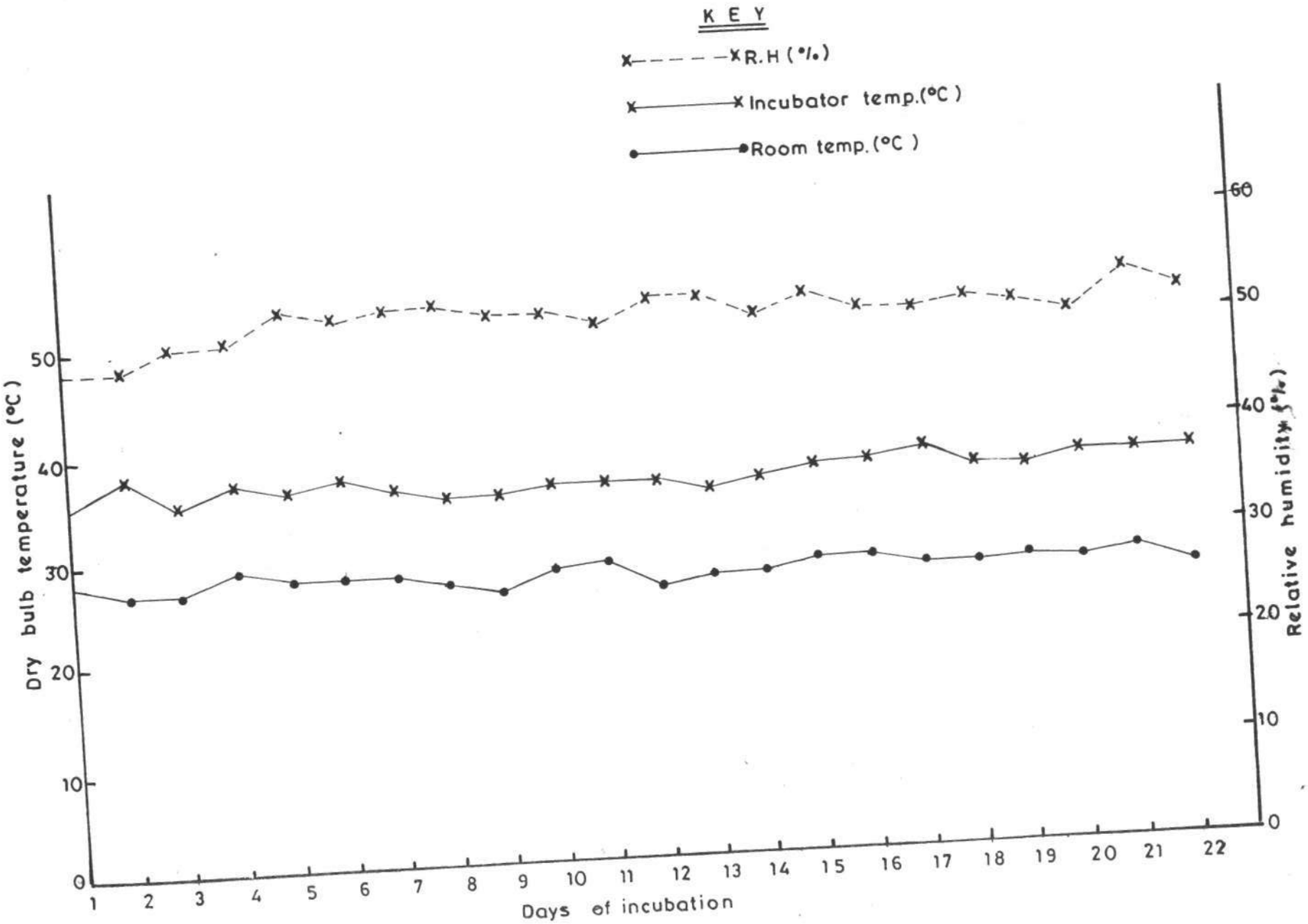


FIG.4.7(b): VARIATION OF THE DRY BULB TEMPERATURES AND RELATIVE HUMIDITY WITH THE DAYS OF INCUBATION

GROUP III

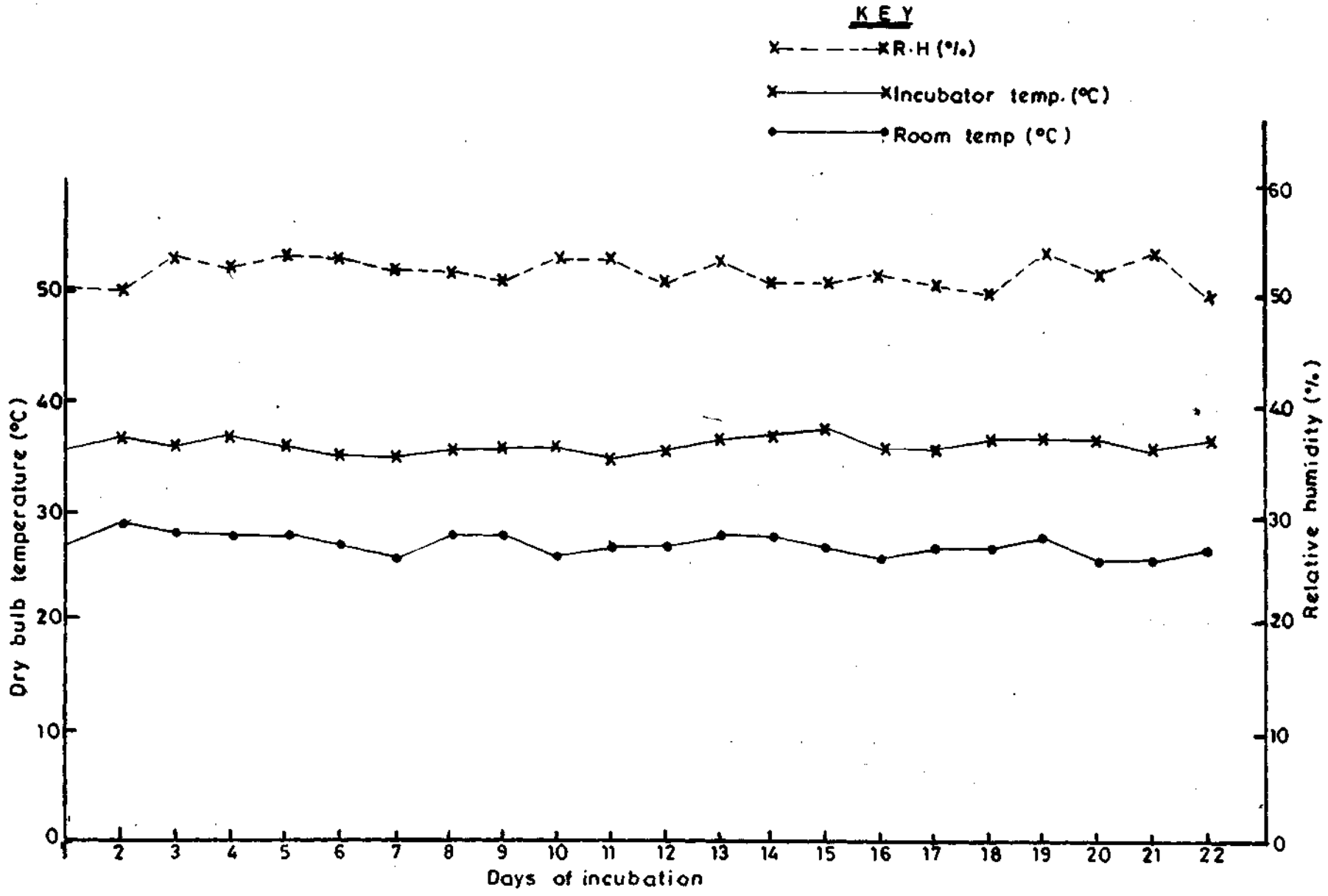


FIG.4.7(c): VARIATION OF THE DRY BULB TEMPERATURES AND RELATIVE HUMIDITY WITH THE DAYS OF INCUBATION.

iii. Hatching Experiment 3

The highest average daily dry bulb temperature values inside the incubator was 38°C, 37°C and 38°C for groups I, II and III respectively. While the lowest value obtained for the three groups was 35°C. Figs 4.7(a), 4.7(b), 4.7(c) gives the variations of the relative humidity and the daily dry bulb temperatures inside the incubator and the room for the groups.

The highest dry bulb room temperature value obtained for the three groups was 29°C and the lowest value was 26°C during the period of incubation. Table 4.5 gives the mean temperatures in the room while Table 4.6 gives the mean temperatures inside the incubator.

The highest relative humidity values inside the incubator was 53%, 54% and 54% for groups I,II and III respectively while the lowest values obtained for the groups were 46%, 48% and 50% respectively.

Many researchers recommended different temperatures for different stages of incubation. Krueger (1977) recommended temperature range between 37.2°C and 37.8°C for the setters and 36.1°C to 36.2°C for the hatchers. Jones (1978) however recommended a range of 37.5°C - 37.8°C for setters and 36.8°C 36.9°C for hatchers. It must be noted that the values given by the authors mentioned are based on the temperate regions and the incubators for which they are reporting are the cabinet

forced convection automated types. Oluyemi and Roberts (1988) reporting on the tropical condition however recommended a temperature of 38°C for a table incubator.

The values of the average daily dry bulb temperatures obtained inside the incubator for the three hatching experiments are adequate for hatching. The low temperature value 35°C obtained during the third hatching experiment may be due to the weather condition as the experiment was conducted during the raining season with the attendant temperature fluctuation due to the weather. It must be noted that the heat supply constant value.

Jones (1978), recommended that the room temperature should be between 21°C to 31°C for the best performance of the incubator the average daily dry bulb temperature obtained inside the room is within the recommended values.

It is interesting to note that the average daily relative humidity obtained during the days of incubation is within the range of 50 - 60% given by Oluyemi and Roberts (1988) for table incubators.

4.3 Effect of Room Temperature on the Incubator Temperature.

The incubator temperature was linearly regressed on the room temperature to determine the relationship between them. The regression equation used was of the form:

$$Y = a + bx$$

where

Y = Incubator temperature (°C)

a = Regression constant

b = Regression coefficient.

x = Room temperature.

Results of the regression analysis are given in Table 4.7. There were very low values of coefficient of determination (R^2) obtained. The highest value was 0.13 for group I at 12.00 noon while the lowest value of 0.013 was obtained respectively for group III at 6.00 am and group I at 6.00 pm.

This result is an assurance that the temperature controller is functionning adequately by regulating the temperature inside the incubator. Also, the continous production of heat by the embryos, the amount which depends on their stages of development, complements the heat supplied at a constant rate by the Kerosine stove.

Table 4.7: Incubator Temperature as a function of the Room Temperature.

	Group	a	b	r	R^2
6.A.M	1	20.5	0.540	0.190	0.036
	11	24.15	0.402	0.134	0.018
	111	26.62	0.304	0.114	0.013
12 NOON	1	25.86	0.380	0.365	0.133
	11	33.10	0.122	0.130	0.017
	111	32.41	0.147	0.186	0.035
6PM	1	34.98	0.089	0.114	0.013
	11	32.41	0.147	0.186	0.035
	111	35.42	0.081	0.121	0.017

N.S - Not significant at 5% level

4.4 Multiple Linear Regression Analysis.

4.4.1 Incubator Temperature as a function of Incubator Relative Humidity and Room Temperature.

Multiple linear regression analysis was performed on the data to obtain the relationship between humidity and temperature and the incubator temperature. The regression equation is of the form

$Y = a + b_w W + b_x x$

Y = Incubator temperature °C

a = Constant

W = Relative humidity inside the incubator (%)

b_w = coefficient of regression of the incubator humidity

x = Room temperature °C

b_x = coefficient of regression of the room temperature.

Results of the multiple linear regression analysis is

presented in Table 4.8 and 4.9.

The partial correlation between the incubator temperature and the incubator humidity at constant room temperature ($r_{yw.x}$) shows a low negative linear relationship -0.29, -0.20 and -0.22 for groups I, II and II respectively. (Table 4.8). Also the partial correlation between the incubator humidity ($r_{yw.x}$) shows a low positive linear relationship 0.30, 0.22 and 0.26 respectively for groups I, II and III.

The multiple correlation coefficient ($r_{yw.x}$) between the incubator temperature, the room temperature and the incubator relative humidity shows a low linear relationship 0.41, 0.37 and 0.31 for groups I,II and III respectively.

The coefficient of determination (R^2) of the regression model gave 0.094, 0.054 and 0.092 for groups I,II and III respectively.

Analysis of variance on the regression model is presented in table 4.9. When the table F values at 1 and 19 degree of freedom were compared with the calculated F values at 5% level of significance, the observed F values, were greater than the calculated values. Hence, the linear relationship between the incubator temperature, incubator relative humidity and the room temperature were not statistically significant at 5% level.

Table 4.8: Multiple Regression Analysis.

Group	a	b_w	b_x	$r_{yx.r}$	$r_{yx.w}$	$r_{y.wx}$
1	33.91	-0.125	0.314	-0.29	0.30	0.413
11	36.3	-0.134	0.251	-0.20	0.22	0.368
111	35.09	-0.111	0.250	-0.22	0.26	0.314

$r_{yw.x}$ = Partial correlation coefficient between y and w for constant x.

$r_{yx.w}$ = Partial correlation coefficient between y and x for constant w

$r_{y.wx}$ = Multiple correlation coefficient between y and w and x.

The partial correlation between the incubator temperature and relative humidity gave a low negative correlation while the partial correlation between the incubator temperature and the room temperature gives a low positive correlation. The multiple linear correlation for the two variables were however positively correlated to the incubator temperature.

The analysis of variance on the multiple linear regression analysis is presented in Table 4.9. The relationship between the incubator temperature and the relative humidity and room temperature were not statistically significant at 5% level.

Table 4.9: ANOVA - Multiple Linear Regression Analysis.

	Source		df	ss	MS	F	R^2
	Regression on x only		1	1.43	1.43	1.94^{NS}	0.094
1	Increase due to adding w		1	1.15	1.15	1.56^{NS}	
	Residual	N-3	19	13.97	0.74		
	TOTAL	N-1	21	15.12			
	Regression on x only		1	0.97	0.97	1.11^{NS}	0.056
11	Increase due to adding w		1	0.65	0.65	0.74^{NS}	
	Residual	N-3	19	15.82	0.879		
	Total	N-1	21	17.44			
	Regression on x only		1	1.26	1.26	2.02^{NS}	0.092
111	Increase due to adding w		1	0.60	0.60	0.96^{NS}	
	Residual	N-3	19	11.84	0.62		
	TOTAL	N-1	21	13.7			

NS - Not significant at 5% level.
x - Room temperature (°C)
wc - Relative Humidity inside the incubator (%).

4.4.2: Incubator Temperature as a function of the Room Relative Humidity and Room Temperature.

Multiple linear regression analysis to simultaneously determine the relationship between the room humidity and temperature on the incubator temperature was carried out. The regression equation is of the form

$$Y = a + b_w W + b_x x$$

where τ = Incubator Temperature

a = Regression constant

W = Relative humidity inside the room

b_w = coefficient of regression of the room humidity.

x = Room temperature

b_x = coefficient of regression of the room temperature.

Results of the multiple regression analysis are presented

in Table 4.10 and 4.11.

The partial correlation between the incubator temperature and the room relative humidity at constant room temperature ($r_{yw.x}$) gave low negative linear relationship -0.03, -0.56 and -0.14 for groups I, II and II respectively. (Table 4.10). Also the partial correlation between the incubator temperature and the room temperature at constant room relative humidity ($r_{yw.x}$) gave a low positive linear relationship 0.27, 0.01 and 0.29 respectively for groups I, II and III.

The multiple correlation coefficient between the incubator temperature, the room relative humidity and the room temperature ($r_{y.wx}$) showed a positive linear relationships 0.31, 0.25 and 0.33 for groups I,II and III respectively.

The coefficient of determination (R^2) of the regression model were 0.088, 0.029 and 0.026 for groups I,II and III respectively.

The analysis of variance on the regression model is presented in table 4.11. When the table F values at 1 and 19 degree of freedom were compared with the calculated F values at 5% level of significance, the observed F values, were greater than the calculated values F values. Hence, the linear relationship between the incubator temperature, and the room relative humidity and the room temperature were not statistically significant at 5% level and then neithr cn be predicted with the knowledge of the other.

The results of the multiple linear regression are presented in

Table 4.10.

Table 4.10 Multiple Regression Analysis

Group	a	b_w	b_x	$r_{yw.x}$	$r_{yx.w}$	$r_{y.wx}$
1	27.52	-4.89×10^{-3}	0.33	-0.03	0.27	0.31
11	28.39	-3.30×10^{-3}	0.28	-0.56	0.01	0.25
111	20.75	-0.042	0.45	-0.14	0.29	0.33

$r_{yw.x}$ = Partial correlation coefficient between y and w for constant x

$r_{yx.w}$ = Partial correlation coefficient between y and x for constant w.

$r_{y.wx}$ = Multiple correlation coefficient between y and w and x.

The analysis shows a low negative partial correlation between the relative humidity inside the room and the incubator temperature and also a low positive partial correlation between the incubator temperature and the temperature inside the room. However, the multiple correlation for the two variables gave a low positive correlation.

The relationship between the incubator temperature and the room relative humidity and room temperature is not statistically significant. The result of the analysis is presented in Table 4.11.

Table 4.11: ANOVA - MULTIPLE LINEAR REGRESSION ANALYSIS.

	Source		df	ss	MS	F
	Regression on x only		1	1.43	1.43	1.98^{NS}
1	Increase due to adding w		1	1.10	1.10	1.52^{NS}
	Residue	N-3	19	13.68	0.72	
	TOTAL	N-1	21	16.20		
	Regression on x only		1	0.49	0.49	2.53^{NS}
11	Increase due to adding w		1	1.04	1.04	1.29^{NS}
	Residual	N-3	19	15.33	0.81	
	TOTAL	N-1	21	16.86		
	Regression on x only		1	0.37	0.36	0.55^{NS}
111	Increase due to adding w		1	1.04	1.04	1.56^{NS}
	Residual	N-3	19	12.66	0.67	
	TOTAL	N-1	21	14.07		

NS - Not significant at 5% level.

4.5 INCUBATION DATA ANALYSIS

4.5.1 Hatching Experiment 1

The result of the first hatching experiment is given in Table 4.12. Out of the 30 hatchable eggs set into the incubator, 5 eggs were infertile and 25 eggs were fertile. After the incubation period, 20 eggs were fully developed with feathers but were dead in shell and 5 eggs had watery contents with blood rings in the broken - out shells.

Table 4.12:Hatching Data for Experiment 1

	No. of eggs set	Percentage of eggs Set (%)
Infertile	5	16.7
Fertile	25	83.3
Dead in shell	20	66.7
Watery	5	16.7
Hatched	0	0

The causes of the embryonic mortality could be as a result of suffocation due to poor ventilation and poor handling during turning and testing, which agree with the Oluyemi report of Oluyemi and Roberts, (1988).

The watery content with blood rings could be as a result of wrong storage of eggs before incubation which caused the early embryonic death which agree with the view of Ogundipe and Oni, (1989).

4.5.2 Hatching Experiment 2.

Table 4.13 presents the result of the second hatching experiment. Out of the 30 hatchable eggs set into the incubator, 26 eggs were fertile and 4 eggs were infertile.

After the days of incubation, 16 eggs were watery with blood rings in the broken-out shells. This suggest an early embryonic death that may be as a result of wrong storage of eggs prior to incubation. Since the record of the eggs as par the time they were laid and the storage conditions were not known, the most probable reasons may be the wrong storage.

Table 4.13:Hatching Data for Experiment 2

	No. of eggs set	Percentage of eggs set (%)
Infertile	4	13.3
Fertile	26	86.7
Dead in shell	10	33.3
Watery	16	53.3
Hatched	0	0

The dead in shell eggs accounted for 10 eggs which may be caused by inadequate turning, handling during turning and violent shaking.

4.5.3 Hatching Experiment 3

Table 4.14 shows the result of the third hatching experiment for the three groups. The number of in fertile eggs were 2,1,2 while the fertile eggs were 7,8,7 for the groups I, II and II respectively.

After the incubation period, groups I and II both have 1 eggs which pipped without emerging out of the shell. This may be as a result of insufficient moisture

Table 4.14 Hatching Experiment 3

Group	I	II	III	Total
Infertile	2	1	2	5
Fertile	7	8	7	22
Pipped	1	1	0	2
Hatched	6	5	4	15
Hatchability(%)	86	63	57	62.5

The number of dead in shell eggs increased with the groups which suggest that wrong storage could be the cause.

The hatchability decreased with the groups with 86%, 63% and 57% obtained for the group I, II and III respectively. The decrease in the number of days of storage before incubation agrees with the views of North (1980); Harper (1980); Jones(1978) and Oluyemi and Roberts (1988) who at various times reported a decrease of hatchability with the days of storage before incubation.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS.

A low cost 60 eggs kerosine fired incubator with heat exchanger located below the eggs having an electromechanical temperature controller was developed.

From the result of the investigation, the following conclusion were drawn.

1) Relative humidity was negatively related to the incubator temperature.
2) There is no statistically significant linear relationship between the incubator temperature and the room temperature.
3) There is no significant linear relationship between the incubator temperature, the incubator relative humidity and the room temperature.
4) There is no significant linear relationship between the incubator temperature, the room humidity and the room temperature.
5) Storage condition of eggs before incubation influence the hatchability. The hatching ability decrease with increase in days of incubation with 86%, 63% and 57% for group I, II and III respectively.
6) The developed control for the kerosine fired incubator performed satisfactorily.

5.2 Recommendations for further studies.

The following recommendations are made as a result of this investigation.

1) Effort should be made to get undiluted kerosine for the test. Too much smoke during incubation is harzadous to the developing embryos.
2) Fertilized eggs should be obtained from reputable and proven breeders. It will be a waste of resources to incubate for 21 days without any hatch.
3) More research work should be carried out on the temperature control in a low temperature condition as in the incubator.
4) Efforts should be devoted to obtaining completely air-tight condition using the volumetric expression of volatile liquid, since the sensitivity is high.

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Appendix A:

Table A (1): Calibration of the Temperature controller

Position	Temperature readings I °C	II °C	Average °C	True position
0	29	30	29.5	≈ 28.0
1	34	36	35.0	≈ 35.0
2	39	41	40.0	≈ 41.0
3	45	47	46.0	≈ 48.0
4	52	55	53.5	≈ 54.0
5	60	61	60.5	≈ 61.0
6	68	70	69.0	≈ 67.0

r1= Temperature readings.
x = Positions of the mirror.

APPENDIX B1: INCUBATION DATA SHEET.
Temperature Records

Days	Date	Room Condition W.B(°C) 6a.m	12noon	6pm	Incubator Condition D.B(°C) 6am	12noon	6pm	W.B(°C) 6am	12noon	6pm	D.B(°C) 6am	12noon	6pm
1	3/2/95	18	18	20	23	24	25	26	27	28	36	37	38
2	4/2/95	18	19	20	23	24	26	26	29	29	35	36	37
3	5/2/95	18	18	19	22	23	25	27	29	28	35	36	36
4	6/2/95	17	18	19	22	24	26	26	27	28	36	37	38
5	7/2/95	17	18	19	22	23	26	27	29	29	36	37	37
6	8/2/95	17	18	19	23	24	26	27	28	29	35	37	38
7	9/2/95	17	19	19	22	24	26	26	27	28	35	36	36
8	10/2/95	18	19	19	24	26	27	28	28	28	35	36	37
9	11/2/95	20	20	21	24	27	29	28	28	29	36	37	38
10	12/2/95	19	20	20	24	26	28	27	29	29	36	36	38
11	13/2/95	20	20	21	25	25	30	26	29	30	36	37	38
12	14/2/95	20	20	21	24	25	28	27	28	28	35	37	38
13	15/2/95	17	18	19	23	26	27	28	29	30	36	36	37
14	16/2/95	17	20	21	23	27	27	27	28	29	35	37	37
15	17/2/95	19	20	20	24	25	28	26	29	29	36	37	38
16	18/2/95	19	20	21	23	27	27	26	29	29	35	37	38
17	19/2/95	19	20	21	23	25	29	26	30	30	35	36	37
18	20/2/95	19	20	21	24	25	27	26	28	29	36	37	38
19	21/2/95	18	19	19	24	28	28	27	30	29	35	36	37
20	22/2/95	17	18	19	24	26	27	26	28	29	36	37	38
21	23/2/95	19	19	20	23	24	25	26	29	29	35	36	36
22	24/2/95	20	20	21	24	27	28	27	29	29	35	36	37

APPENDIX B2: INCUBATION DATA SHEET.

Temperature Records

Days	Date	Room Condition W.B(°C)			Room Condition D.B(°C)			Incubator Condition W.B(°C)			Incubator Condition D.B(°C)		
		6a.m	12noon	6pm	6am	12noon	6pm	6am	12noon	6pm	6am	12noon	6pm
1	16/3/95	21	21	21	29	30	31	26	27	28	36	37	38
2	17/3/95	20	21	22	29	31	32	26	29	29	35	36	37
3	18/3/95	22	23	24	28	29	30	27	29	28	35	36	37
4	19/3/95	21	23	24	29	30	31	26	27	28	36	37	38
5	20/3/95	20	22	23	29	29	30	27	29	29	36	37	38
6	21/3/95	20	21	22	28	29	31	27	28	29	35	37	38
7	22/3/95	21	23	24	29	30	31	26	27	28	35	36	36
8	23/3/95	22	23	24	29	29	30	28	28	38	35	36	37
9	24/3/95	22	23	24	28	29	30	28	28	29	36	37	37
10	25/3/95	22	23	24	30	31	32	27	29	29	36	36	38
11	26/3/95	22	24	24	29	31	32	26	29	30	36	37	38
12	27/3/95	21	23	24	28	29	29	27	28	28	35	37	39
13	28/3/95	21	23	24	29	30	31	26	27	28	35	36	36
14	29/3/95	22	23	24	29	30	31	27	28	29	35	37	37
15	30/3/95	22	23	24	29	31	32	26	29	29	36	37	38
16	31/3/95	21	23	24	28	29	30	26	29	29	35	37	38
17	01/4/95	21	23	24	29	29	30	26	29	29	35	37	38
18	02/4/95	21	23	24	29	30	30	26	28	29	36	37	38
19	03/3/95	21	22	23	29	31	31	27	30	29	35	36	37
20	04/3/95	20	22	24	30	31	32	26	28	29	36	37	38
21	05/3/95	21	22	23	29	30	31	26	29	29	35	36	36
22	06/3/95	22	23	24	29	30	31	27	29	29	35	36	37

APPENDIX B:3a INCUBATION DATA SHEET.
Temperature Records **GROUP I**

Days	Date	INC D.B 6a.m	INC D.B 12noon	INC D.B 6pm	INC W.B(°C) 6am	INC W.B(°C) 12noon	INC W.B(°C) 6pm	ROOM D.B(°C) 6am	ROOM D.B(°C) 12noon	ROOM D.B(°C) 6pm	ROOM W.B(°C) 6am	ROOM W.B(°C) 12noon	ROOM W.B(°C) 6pm
1	8/7/95						27			28			26
2	9/7/95	35	37		26	26	26	25	28	28	24	26	27
3	10/7/95	34	35		25	26	26	26	28	29	22	23	25
4	11/7/95	37	39		25	30	28	26	27	28	22	23	24
5	12/7/95	33	37		25	28	27	25	28	29	23	23	25
6	13/7/95	35	37		24	28	29	26	30	30	24	25	25
7	14/7/95	34	35		26	27	29	26	29	29	23	25	24
8	15/7/95	36	37		26	28	29	26	28	29	23	24	24
9	16/7/95	32	37		27	29	29	26	29	29	23	24	24
10	17/7/95	34	35		24	27	27	26	27	28	23	24	24
11	18/7/95	33	35		26	26	28	25	26	27	23	23	24
12	19/7/95	34	35		25	27	29	26	29	28	23	23	23
13	20/7/95	35	36		25	27	28	26	29	30	23	25	25
14	21/7/95	33	37		26	28	29	25	26	27	23	24	24
15	22/7/95	32	35		25	26	28	26	27	27	23	23	23
16	23/7/95	34	36		25	27	29	25	28	28	22	23	25
17	24/7/95	35	37		26	29	29	26	29	29	24	25	25
18	25/7/95	36	38		27	29	29	26	28	29	23	25	25
19	26/7/95	37	38		28	29	29	25	29	28	22	24	24
20	27/7/95	33	36		25	27	29	25	26	26	22	24	23
21	28/7/95	34	36		25	28	29	25	28	29	22	24	25
22	29/7/95	35	37		26	28	29	26	28	27	23	24	23

Appendix B: 3b Incubation Data Sheet
Table b: 2 Temperature Records **GROUP II**

Days	Date	INC D.B(°C) 6a.m	INC D.B(°C) 12noon	INC D.B(°C) 6pm	INC W.B(°C) 6am	INC W.B(°C) 12noon	INC W.B(°C) 6pm	ROOM D.B(°C) 6am	ROOM D.B(°C) 12noon	ROOM D.B(°C) 6pm	ROOM W.B(°C) 6am	ROOM W.B(°C) 12noon	ROOM W.B(°C) 6pm
1	10/7/95	34	35		25	26	26	26	28	29	22	23	25
2	11/7/95	37	39		25	30	28	26	27	28	22	23	24
3	12/7/95	33	37		24	28	27	25	28	29	23	25	25
4	13/7/95	35	37		26	28	29	26	30	30	24	25	25
5	14/7/95	34	36		26	27	29	26	29	29	23	24	24
6	15/7/95	36	37		27	28	29	26	28	29	23	24	24
7	16/7/95	32	37		24	29	29	26	29	29	23	24	24
8	17/7/95	34	35		26	27	27	26	27	28	23	23	24
9	18/7/95	33	35		25	26	28	25	26	27	23	23	24
10	19/7/95	34	35		25	27	29	26	29	28	23	25	23
11	20/7/95	35	36		26	27	28	26	29	30	23	24	25
12	21/7/95	33	37		25	28	29	25	26	27	23	23	24
13	22/7/95	32	35		25	26	28	26	27	27	23	23	23
14	23/7/95	34	36		25	27	29	25	28	28	22	25	25
15	24/7/95	35	37		26	29	29	26	29	29	24	25	25
16	25/7/95	36	38		27	29	29	26	28	29	23	24	25
17	26/7/95	37	38		28	29	29	25	29	28	22	24	24
18	27/7/95	33	36		25	27	29	25	26	26	22	24	23
19	28/7/95	34	36		25	28	29	25	28	29	22	24	25
20	29/7/95	37	37		26	28	29	26	28	27	22	24	23
21	30/7/95	37	37		27	29	30	26	28	29	22	24	24
22	31/7/95	36	37		27	28	29	25	26	27	22	24	25

Appendix B: 3c Incubation Data Sheet **GROUP III**
Table b: 3 Temperature Records

Days	Date	INCUBATOR D.B(°C) 6a.m	12noon	6pm	W.B(°C) 6am	12noon	6pm	ROOM D.B(°C) 6am	12noon	6pm	W.B(°C) 6am	12noon	6pm
1	12/7/95	33	37	[illegible]	24	28	27	25	28	29	[illegible]	25	2[illegible]
2	13/7/95	35	37	[illegible]	26	28	29	26	30	30	[illegible]	25	2[illegible]
3	14/7/95	34	36	[illegible]	26	27	29	26	29	29	23	24	24
4	15/7/95	36	37	[illegible]	27	28	29	26	29	29	23	24	24
5	16/7/95	32	37	[illegible]	24	29	29	26	29	29	23	24	2[illegible]
6	17/7/95	34	35	36	26	27	27	26	27	28	23	23	24
7	18/7/95	33	35	37	25	26	28	25	26	27	23	23	24
8	19/7/95	34	35	38	25	27	29	26	29	28	23	25	23
9	20/7/95	35	36	37	26	27	28	26	29	30	23	24	25
10	21/7/95	33	37	38	25	28	29	25	26	27	23	23	24
11	22/7/95	32	35	37	25	26	28	26	27	27	23	23	23
12	23/7/95	34	36	38	25	27	29	25	28	28	22	25	25
13	24/7/95	35	37	[illegible]	26	29	29	26	29	29	[illegible]	25	2[illegible]
14	25/7/95	36	38	[illegible]	27	29	29	26	28	29	[illegible]	24	2[illegible]
15	26/7/95	37	38	38	28	29	29	25	29	28	22	24	24
16	27/7/95	33	36	38	25	27	29	25	26	26	22	24	23
17	28/7/95	34	36	[illegible]	25	28	29	25	28	29	22	24	2[illegible]
18	29/7/95	35	37	[illegible]	26	28	29	26	28	27	23	24	2[illegible]
19	30/7/95	36	37	[illegible]	27	29	30	26	28	29	22	24	24
20	31/7/95	36	37	[illegible]	27	28	29	25	26	27	22	24	25
21	1/8/95	34	36	[illegible]	26	28	29	25	26	27	22	24	2[illegible]
22	2/8/95	35	38	37	26	29	28	25	28	27	23	24	
24													

APPENDIX C

MULTIPLE REGRESSION ANALYSIS.
TABLE E 1: Incubator temperature as a function of the incubator humidity and Room temperature.

	I			II			III		
	T_i	H_i	T_o	T_i	H_i	T_o	T_i	H_i	T_o
1	36.0	50.5	28.0	[illegible]	48.0	27.7	35.3	50.0	27.[illegible]
2	36.3	46.0	27.0	37.7	48.0	27.0	37.0	50.0	28.7
3	35.3	48.0	27.7	35.3	50.0	27.3	36.0	53.0	28.0
4	37.7	48.0	27.0	37.0	50.0	28.7	37.0	52.3	27.7
5	35.3	50.0	27.3	36.0	53.0	28.0	35.7	53.0	28.0
6	37.0	50.0	28.7	37.0	52.0	27.7	35.0	53.0	27.0
7	36.0	53.0	28.0	[illegible]	53.0	28.0	35.0	52.0	26.0
8	37.0	52.0	27.7	[illegible]	53.0	27.0	35.7	52.0	27.7
9	35.7	53.0	28.0	35.0	52.0	26.0	36.0	51.0	28.3
10	35.0	53.0	27.0	35.7	52.0	27.7	36.0	53.0	26.0
11	35.0	52.0	26.0	36.0	51.0	28.3	34.7	53.0	26.7
12	37.5	52.0	27.7	36.0	53.0	26.3	36.0	51.0	27.0
13	36.0	51.0	28.3	34.7	53.0	26.7	36.7	53.0	28.0
14	36.0	53.0	26.0	36.0	51.0	27.0	37.3	51.0	27.7
15	34.7	53.0	26.7	36.7	53.0	28.0	37.7	51.0	27.3
16	36.0	51.0	27.0	37.3	51.0	27.7	35.7	52.0	25.7
17	36.7	53.0	28.0	37.7	51.0	27.3	36.0	51.0	27.3
18	37.3	51.0	27.7	35.7	52.0	25.7	36.7	50.0	27.0
19	37.7	51.0	27.3	36.0	51.0	27.3	37.0	54.0	27.7
20	35.7	52.0	25.7	[illegible]	50.0	27.0	37.0	52.0	26.0
21	36.0	51.0	27.3	37.0	54.0	27.7	36.0	54.0	26.0
22	36.7	50.0	27.0	37.0	52.0	26.0	36.7	50.0	26.7

$Ti = F (Hi, To)$

$$Ti = F\ (Hi,\ To)$$

Where

y = Ti = Temperature inside the incubator (^{0}C)

w = Hi = Relative humidity inside the incubator (%)

x = To = Temperature inside the room where the incubator is located (^{0}C)

$Y = 36.1\ \ \Sigma Y = 794.8\ \ \Sigma Y^{2} = 28729.08$

$W = 51.1\ \ \Sigma W = 1123.5\ \ \Sigma W^{2} = 57449.25$

$x = 27.3\ \ \Sigma x = 601.1\ \ \Sigma x^{2} = 16435.99$

$\Sigma yw = 40578.9\ \ \Sigma yx = 21720.29\ \ \Sigma wx = 30694.8$

$cyy = \Sigma y^{2} - 1/n(\Sigma y)^{2} = 28729.08 - 1/22\ (797.8)^{2}$
$= 15.12$

$cww = \Sigma w^{2} = \Sigma w^{2} - 1/n\ (\Sigma w)^{2} = 57449.25 - 1/22\ (11235)^{2}$
$= 74.15$

$Cxx = \Sigma x^{2} - 1/n\ (\Sigma x)^{2} = 16435.99 - 1/22(601.1)^{2}$
$= 12.30$

To obtain the regression coefficient.

$$b_w = \frac{CxxC_{yw} - CnxC_{wx}}{Cww\ Cxx - Cw^2_{wx}} = \frac{(12.30)(-10.09) - (4.19)(-2.58)}{(74.15)(12.30) - (-2.58)^2}$$

$$= 0.314$$

$$a = \ddot{y} - w\ b_w - \tilde{n}\ b_x = 36.1 - (51.1)(-0.125) - (27.3)(0.314) = 33.91$$

$$y = 33.91 - 0.125W + 0.314\ x$$

$$T_i = 33.91 - 0.125\ Hi + 0.314\ To$$

The multiple correlation coefficient $R_{y.wx}$ between y and w and x is $R^2_{y.wx} = \frac{b_w C_{yw} + bxC_{yx}}{C_{YY}}$

$$= \frac{(-0.125)(-10.09) + (0.314)(4.19)}{15.12}$$

$$= 0.413$$

The analysis of variance of multiple regression.

"Due to regression of y on w only" ss $= \frac{C^2_{yw}}{C_{ww}}$

$$= \frac{(-10.09)^2}{74.15}$$

$$= 1.373$$

"Due to regression y on μ only " ss

$$= C^2_{yx} \frac{(4.19)^2}{C_{xx}} = \frac{}{12.30}$$

$$= 1.427$$

" Due to multiple regression of y on w and x"

$$ss = b_w\ C_{yw} + b_x C_{yx}$$

$$= (-0.125)(-10.09) + (0.314)(4.19) = 2.577$$

" Increase due to adding w (one with smaller ss) to regression after x (one larger ss)" ss

="Due to w and x" ss - "Due to x" ss

= 2.577-1.427 = 1.15

Total ss = C_{yy} = 15.12

"About multiple regression " (Residual) ss

= Total ss - "Due to w and μ" ss

= 15.12 - 1.15 = 13.97.

Table C2 ANOVA - Multiple Regression Data.

Source	d.f	ss	Ms	F
Regression on μ only	1	1.427	1.427	1.94^{NS}
Increase due to adding w	1	1.15	1.15	1.56^{NS}
Residual N-3	=19	13.97	0.735	
Total	21	15.12		

The same procedure is followed in calculating the relationship between temperature inside the incubator and the relative humidity inside the incubator and the room temperature simultaneously for the other two groups.

APPENDIX C2

MULTIPLE REGRESSION ANALYSIS.

TABLE E 3: Incubator temperature as a function of the incubator humidity and Room temperature.

	1			11			111		
	T_i	H_i	T_o	T_i	H_o	T_o	T_i	H_i	T_o
1	36.0	85.0	28.0	35.3	70.7	27.7	35.3	79.0	27.3
2	36.3	90.0	27.0	37.7	72.0	27.0	37.0	73.7	28.7
3	35.3	70.7	27.7	35.3	79.0	27.3	36.0	70.7	28.0
4	37.7	72.0	27.0	37.0	73.7	28.7	37.0	72.3	27.7
5	35.3	79.0	27.3	36.0	70.7	28.0	35.7	70.7	28.0
6	37.0	73.7	28.7	37.0	72.3	27.7	35.0	74.0	27.0
7	36.0	70.7	28.0	36.0	70.7	28.0	35.0	80.3	26.0
8	37.0	72.3	27.7	35.0	74.0	27.0	35.7	73.0	27.7
9	35.7	70.7	28.0	35.0	80.3	26.0	36.0	71.0	28.3
10	35.0	74.0	27.0	35.7	73.0	27.7	36.0	80.3	26.0
11	35.0	80.3	26.0	36.0	71.0	28.3	34.7	74.0	26.7
12	37.5	73.0	27.7	36.0	80.3	26.3	36.0	78.7	27.0
13	36.0	71.0	28.3	34.7	74.0	26.7	36.7	77.0	28.0
14	36.0	80.3	26.0	36.0	78.7	27.0	37.3	74.7	27.7
15	34.7	74.0	26.7	36.7	77.0	28.0	37.7	72.3	27.3
16	36.0	78.7	27.0	37.3	74.7	27.7	35.7	80.3	25.7
17	36.7	77.0	28.0	37.7	72.3	27.3	36.0	74.7	27.3
18	37.3	74.7	27.7	35.7	80.3	25.7	36.7	74.3	27.0
19	37.7	72.3	27.3	36.0	74.7	27.3	37.0	70.0	27.7
20	35.7	80.3	25.7	36.7	74.3	27.0	37.0	82.7	26.0
21	36.0	74.7	27.3	37.0	70.0	27.7	36.0	82.7	26.0
22	36.7	74.3	27.0	37.0	82.7	26.0	36.7	78.7	26.7

$$Ti = f\ (H_o,\ T_o)$$

Where

$y = Ti$ = Temperature inside the incubator (°C)

$w = H_o$ = Relative humidity inside the room (%)

$x = T_o$ = Temperature inside the room where the incubator is located (°C)

$Y = 36.1\ \Sigma Y = 794.8\ \ \Sigma Y^2 = 28729.08$

$W = 75.9\ \Sigma W = 1668.7\ \Sigma W^2 = 127101.37$

$x = 27.3\ \Sigma x = 601.1\ \ \Sigma x^2 = 16435.99$

$\Sigma yw = 60272.04\ \Sigma yx = 21720.29\ \Sigma wx = 45559.99$

$cyw = -1^3.54 \quad Cyx = 4.19 \quad Cwx = -33.45$

$Cyy = 15.12$

$cww = 530.48$

$Cxx = 12.30$

$$Byw = Cyy\ Cww = 8020.86$$

$$r_{yw} = -0.151$$

$$B_{yx} = CyyCxx = 185.98$$

$$r_{yw} = 0.307$$

$$B_{wx} = C_{ww}\ C_{xx} = 6524.90$$

$$r_{wx} = -0.414$$

The partial correlation coefficient between y and w for constant x

$$r_{yw.x} = \frac{r_{yw} - r_{yx}\ r_{wx}}{\sqrt{(1-r^2_{yx})}\sqrt{(1-r^2_{wx})}}$$

$$= \frac{-0.151-(0.307)(-0.414)}{\sqrt{(0.307)^2)}\sqrt{1-(-0.414)^2}}$$

$$r^{yw.x} = \frac{-0.0239}{(0.952)(0.910)} = -0.028$$

The partial correlation coefficient between y and x for constant w is

$$r^{yw.x} = \frac{r^{yx} - r^{yw}\ \tau^{yx}}{\sqrt{(1-\tau 2^{yw})}\ \sqrt{(1-\tau 2^{wx})}}$$

$$r^{y\mu.w} = \frac{0.307 - (-0.151)(0.414)}{\sqrt{1-(-0.151)2}\ \sqrt{1-(-0.414)2}}$$

$$= \frac{0.2445}{(0.989)(0.910)} = 0.272$$

To obtain the regression coefficients

$$bw = \frac{Cxx\ Cyw - Cyx\ Cwx}{CwwCxx - Cw2x}$$

$$bw = \frac{12.30(-13.54) - (4.19)(-33.45)}{(530)(12.30) - (-33.45)2} = \frac{26.3}{5400.10}$$

$$= -4.89 \times$$

$$b\mu = \frac{Cww\ Cyx - Cyw\ Cwx}{Cww\ Cxx - C2wx}$$

$$= \frac{(530.48)(4.19) - (-13.54)(-33.45}{5400.10}$$

$$= 0.328$$

$$a = y - wbw - \mu b\tau = 36.1 - 75.9(-4.89x10\text{-}3) - 27.3(0.328)$$

$$= 27.52$$

$$y = 27.52 - 4.89 \times 10\text{-}3\ W + 0.328\ x$$

$$Ti = 27.52 - 4.89 \times 10\text{-}3\ Ho + 0.328\ To$$

The multiple correlation coefficient Ry.wx between y and w and

x is

$$R2y.wx = \frac{bw\ Cyw + bxCyx}{Cyy}$$

$$= \frac{-4.89 \times 10\text{-}3\ (-13.54) + (0.328)(4.19)}{15.12}$$

$$= 0.095 \quad R = 0.309$$

The ANOVA of multiple regression " Due to regression of y on w only" ss

$$= \frac{C2yw}{Cww} = \frac{(-13.54)2}{530.48}$$

$$= 0.346$$

"Due to regression of y on x only" ss

$$= \frac{C2yx}{Cxx} = \frac{(4.192}{12.30} = 1.427$$

"Due to multiple regression of y on w and μ" ss

= bw Cyw + bμCyx
= (-4.89 x 10-3)(-13.54) + (0.328)(4.19)

= 1.44

"Increase due to adding w + 0 regression after x"

= "Due to w and x" ss - "Due tp x" ss

= 1.44 - 0.346 = 1.095

Residual = Total ww - "Due to w and x" ss = 15.12 - 1.44

= 13.68

Table C4 ANOVA - Multiple Regression Data.

Source	d.f	ss	Ms	F
Regression on x only	1	1.427	1.427	1.98NS
Increase due to adding w	1	1.095	1.095	1.52NS
Residual N-3	=19	13.68	0.72	
Total	N-1 21	15.12		

The same procedure is followed in calculating the relationship between the incubator temperature and the relative humidity and the temperature inside the room where the incubator is located for the other two groups.

APPENDIX F

Hatchability calculation.

Total number of eggs set = 27

Number of fertile eggs = 24

Number of fertile eggs that hatched = 15

Percentage fertile eggs that hatched

$$= \frac{\text{Number of eggs that hatched} \times 100}{\text{Total number of eggs set}} \quad 1$$

$$= \frac{15}{24} \times \frac{100}{1} = 62.5\%$$