DESIGN AND CONSTRUCTION OF SOLAR INCUBATOR

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Abstract
Birds incubators enable large production of birds. Cost of this production is getting out of hands lately due to the energy crisis being experienced globally. This results in the increase in the cost of chicken production and unaffordable to common man. In order to surmount this challenge and even encourage the rural farmer to go into bird production that will guarantee protein supplement for him and his family, it is necessary to look at other ways of generating energy for egg incubation. Solar energy is chosen because it is free, abundant and clean and can be tapped anywhere in the country. The solar incubator has been designed and constructed. Test of its performance and modification will be reported in the part two of the paper. The solar incubator consists of a solar collector which heats water that in turn heats an incubating chamber for the process of fowl hatching. It is designed to work for 24 hours and it has a built-in heat storage facility that supplies heat to the incubating chamber during the period of the day that there is no solar energy.

Keywords: birds, incubators, solar energy, hatching

Nomenclatures

A	=	*area*
C_P	=	*specific heat capacity, air, water*
Q_U	=	*Useful energy gain by the collector*
Q_L	=	*Rate of energy loss from the collector*
Q_S	=	*Rate of energy storage in the collector*
Q_w	=	*Rate of energy stored in the water tank*
Q_{vent}	=	*Energy loss due to ventilation*
Q_{inc}	=	*Energy required in the incubator*
Q_{conv}	=	*Convective energy*
Q_{rad}	=	*Radiation energy*
V_{ch}	=	*Ventilating rate of at chick emergence*
A_p	=	*Area of pipe*
A_s	=	*Incubator surface area*
A_v	=	*Area of ventilation*
D_p	=	*Diameter of pipe*
H_C	=	*Total energy incident on collector plane*
A_C	=	*Area of collector*
D	=	*diameter*
E	=	*energy*
T_w	=	*Temperature of water in the storage tank*
F'	=	*collector efficiency*
F_R	=	*collector heat removal factor*
F''	=	*collector flow factor*
G	=	*mass flow rate per unit area*
I_{SC}	=	*solar constant*
H	=	*total energy incident on the horizontal plane*
H_b	=	*beam component of solar energy incident on the plane of measurement*
H_d	=	*diffuse component of solar energy incident on the plane of measurement*
H_o	=	*solar radiation outside the atmosphere*
H_T	=	*solar radiation on a tilted surface*
h	=	*heat transfer coefficient*
κ	=	*extinction coefficient*

K_a	=	*Thermal conductivity of air*
K_{wo}	=	*Thermal conductivity of wood*
K_w	=	*Thermal conductivity of water*
N	=	*number of covers*
S	=	*absorbed solar energy per unit area*
W	=	*distance between tubes*
α	=	*absorptance*
γ	=	*Azimuth angle*
δ	=	*Plate thickness*
ε	=	*emittance*
η	=	*efficiency*
ρ	=	*reflectance*
σ	=	*Stefan – Boltzman constant*
τ	=	*transmittance*
ϕ	=	*latitude*
ω	=	*sunset solar hour angle*

Introduction

Energy conservation has always been an important issue among the scientists and policy makers. Seeking a viable alternative energy source has always been the centre of attention particularly in the agricultural sector. The use of solar energy has been gaining significance as a continuous supply of alternative power source, which seems to have an answer to frequent power constraints faced by farmers. Continuous supply of conventional energy in Nigeria is a mirage, due to frequent power outage. Several researchers have worked on solar energy. Notable among them are Adeyemo (1988), Fagbenle (1990), Pelemo et al (2002) who worked on estimation of daily radiation in Nigeria using meteorological data.

Owokoya (1992) designed and constructed solar air heater. Adaramola et al (2001) worked on solar cooker and was able to generate and maintain temperature up to 170^oC. Odia (2006) effectively designed solar assisted refrigeration system.

The world's population is growing at an alarming rate and so is the demand for protein especially in the rural areas. Poultry is a good source of protein if it is affordable. The production level is limited with natural incubation because the number of eggs an adult female bird lays in a year vary from none to 365 or one per day (French,1981). But a broody hen (a hen that wants to set and hatch eggs and raise the chicks) can hatch just about 10-12 eggs at once in 21 days (French, 1981), which reduces its productivity as it takes time to incubate and hatch the chicks. For the world growing population, relying on this natural type of incubation is not enough, hence the need for artificial incubation. This way, a female bird just concentrates on laying eggs while the incubation is done artificially.

Parameters like temperature, relative humidity, ventilation, position of egg and egg turning affect incubation greatly and so, success of artificial incubation depends on how one is able to control these (Oluyemi and Roberts, 1979). Heating is the most critical of the parameters considered; in fact what mainly separates the types of incubation is mainly the method of heating adopted. A temperature range of 37.2^oC to 39.4^oC was recommended for proper incubation (Oluyemi and Roberts,1979). Temperature control is the most vital part of incubation because too much heat will cause the eggs to crack open prematurely, too little means a late hatch, if the temperature is excessive when the chick emerges, its down feather (small feathers covering a chick to keep it warm) sticks to the shell. Overheating may also damage its essential food store (the yolk) or prevent it from passing through the fine ducts into the chick's intestine in which case death will result in a few days. The correct level of humidity is especially important early in incubation when the air cell is being formed by the evaporation of water through the shell. Too much or too little moisture in the surrounding air will cause the air space to be too large or too small and the chick will die during the last three days of growth or while hatching even if all other conditions have been perfectly maintained. Oluyemi and Roberts, (1979) also recommended a relative humidity of 55%- 60% for adequate egg hatching. An incubating egg requires oxygen to live and develop and it produces carbon dioxide and several poisonous gases. Therefore good circulation and ventilation are essential, on the other hand, excessive drafts will cause changes in eggs temperature and too much evaporation of moisture so there is need for proper control.

Several sources of energy have been used in the past for the process of artificial incubation - electricity for electric incubator, incubator using kerosene lantern as a source of heat, e.t.c. Adewumi (1998) designed and constructed a laboratory scale incubator using locally available materials and kerosene lantern as heat source.

Kerosene and electricity as sources of heat in incubation are not affordable to the rural dwellers because of the cost and irregular nature. There is need to provide very cheap and highly abundant source of energy to this group for their poultry incubation. It will enable a rural man to be self sufficient in having fresh meat stocks and eggs that he can generate on a monthly basis, for not only will it feed his family, but he can help his friends and also have spare food to exchange for other items if necessary.

The objective of this work is to design a solar incubator for the purpose of meeting the protein needs of the world rural populace using locally available materials.
Solar energy is cheap clean and in abundance in Nigeria. So designing an incubator that will be powered by the sun is a very positive initiative.

General Description of A Solar Incubator
The solar egg incubator is composed of two main components; the solar water heater and the incubator. The solar water heater consists of the solar collector, a hot water storage tank, and the piping system. The flat plate collector which is an active solar heating system is made up of three basic components; the cover plate, the absorber and the casing. The cover plate is a transparent medium which allows the passage of short wave visible radiation. The absorber plate is a black body, which absorbs the visible radiation and converts it to a long wave radiation, the black body emits this radiation back, the cover plate does not allow the passage of long wave radiation, so it is reflected back onto the absorber and it strikes the absorber again and again leading to a heat build-up in the collector (a green house effect), to utilize this heat a fluid is passed through pipes brazed on the absorber plate and the heat is drawn away into the fluid. The fluid medium is mostly air or water.
The hot water produced is now moved by thermo-siphon principle. The system is shown in Fig. 1, it makes use of capillary system. Cold water has a higher specific density than warm water; it is therefore heavier and sinks to the bottom while the warm water rises through the capillary tube. The collector is mounted below the hot water storage tank, so, cold water from the tank flows to the solar collector through a descending water pipe and hot water from the collector flows to the tank by thermo- siphon process through the ascending pipe. The water in the tank is now sent through a copper tubing which serves as a heat exchanger into the incubator.

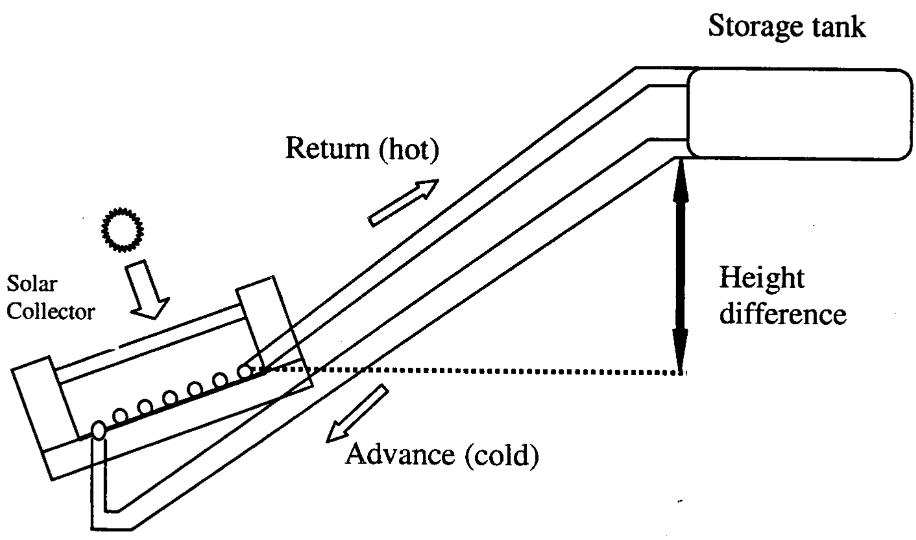


Fig. 1 Schematic Diagram of a Thermo-siphon System

Theoretical Analysis
The performance of a solar collector is described by an energy balance equation that indicates the distribution of incident solar energy into useful energy gain and various loses. The energy balance on the whole collector can be written as:

$$A_C\{[HR(\tau\alpha)]_{beam} + [HR(\tau\alpha)]_{diffuse}\} = Q_U + Q_L + Q_S \quad 1$$

When Q_s, which is the rate of energy storage is neglected, Q_U (useful energy gain) is obtained considering the collector overall heat transfer coefficient, temperature distribution between tubes, the collector heat removal factor, flow factor, mean plate temperature and the effects of heat capacity of the collector as

$$Q_U = A_C F_R R(\tau\alpha)(H - H_C) \quad 2$$

The transmittance absorbance product, $\tau\alpha$, which is also called the optical efficiency describes the collector efficiency without any loses due to convection or heat radiation. This is only the case if the absorber temperature is equal to the ambient temperature, and for any surface transparent to the incident radiation at any degree, the sum of absorbance, reflectance and transmittance must be equal to unity. R is relative humidity.

Ratio of Total Radiation on a Tilted Surface to that on a Horizontal Surface R

For any surface the maximum available radiation is obtained when the sun's incidence is normal to the plane of the plate. This is approximately so at the noon of the location. In order not to be tracking the sun every now and then it is necessary to find a fixed value of tilt that will absorb radiation higher than that possible were the surface horizontal through the day, though not as high as when hourly tracking of the sunrays is adopted. For optimum tilt angle Fagbenle (1990) suggested, $\phi + 10^o$ for locations with latitude $< 8.5^o$ N. Therefore the optimum possible tilt angle for Abeokuta is approximately 17.2^o

The correction factor R is given by $R = \frac{H_T}{H} = \frac{H_n \cos\theta_T}{H_n \cos\theta_Z} = \frac{\cos\theta_T}{\cos\theta_Z}$ 3

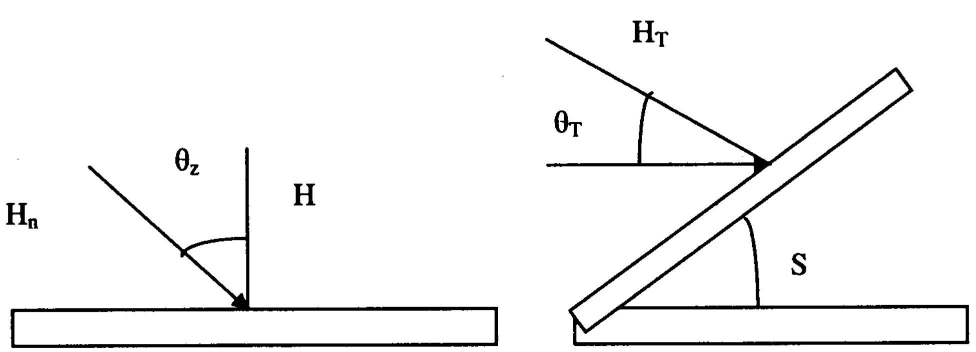


Fig. 3

Radiation on horizontal and tilted surfaces

$$\cos\theta = \sin\phi\sin\delta\cos s - \sin\delta\cos\sin s\cos\gamma + \cos\delta\cos\phi\cos s\cos\omega + \cos\delta\sin\phi\sin s\cos\gamma\cos\omega + \cos\delta\sin s\sin\gamma\sin\omega \quad 4$$

Where,

ω = sun set hour angle

ϕ = latitude, $7.2^o N$

δ = declination angle

γ = surface azimuth angle

s = angle of tilt, $17.2^o N$

θ_Z is the zenith angle, the angle between the beam from the sun and the vertical

The collector heat removal factor
This is a quantity that relates the actual useful energy gain of a collector to the gain if the collector were at the fluid inlet temperature.

The Storage Tank
Water is used as the storage medium because it is cheap, highly available and has high thermal capacity. For a non-stratified tank, Olaleye (2008) gave the energy balance in the tank as

$$(MC_p)\frac{dT_s}{d\tau} = Q_U - Q_L - UA(T_s - T) \quad (5)$$

i.e. Rate of energy transfer into the tank = the rate of energy build up in the tank + the rate of energy leaving the tank

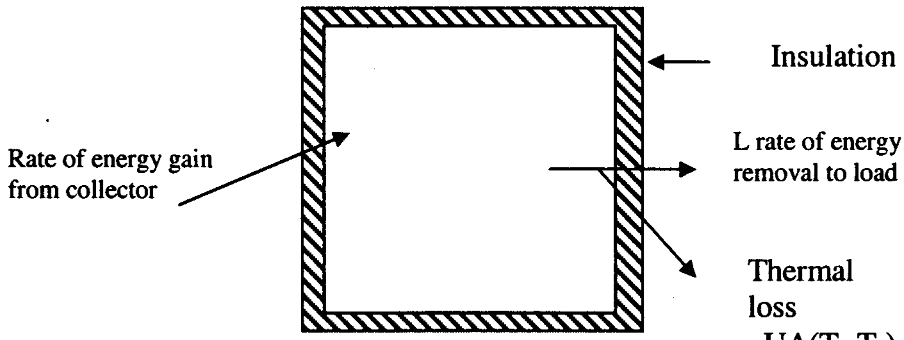


Fig. 4 Unstratified Storage Tank

The Incubator
For natural convection, there is no particular velocity, flow is as a result of energy transfer between the tube at temperature T_1 and T_2. The fluid properties of interest are ρ, μ, C_p, κ, β. The last property listed is the coefficient of thermal expansion, which is used to represent the variation in fluid density with temperature according to

$$\rho = \rho_o(1 + \beta\Delta T) \quad (6)$$

where ρ_o is a reference density inside the heated layer and ΔT is the temperature difference between the fluid and the plate surface and that far removed from the plate.
The buoyant force per unit volume F_B may be written as

$$F_B = (\rho - \rho_o)g \quad (7)$$

Therefore β,g and ΔT are included in a dimensional analysis of natural convection, Holman (2002), a representation of natural convection heat transfer data in dimensionless form is

$$Nu = f(Gr, \Pr) \quad (8)$$

where, Nu = Nusselt number
Gr = Grashof number
Pr = Prandtl number

In natural convection the flow is produced by buoyant effects resulting from temperature difference. The effects are included in Grashof's number

Design and Construction
Materials Selection
The components of the solar incubator include a solar collector, a hot water storage tank, the incubator and the piping system.

For the collector, the casing is made of wood for lighter weight and to provide insulation for the absorber. The glass is a clear glass of 4mm thickness. Glass is preferred to plastic because of its high transmissivity and a higher resistance to heat build up.

The absorber plate is made of mild steel because of its good conductivity and being relatively cheap. Welded to the absorber plate are copper pipes of 13mm external diameter. The pipes were cut into sizes, drilled and brazed together with oxyacetylene flame, brazing rod and brazing powder. The surface was painted with tar to increase its absorptivity. The paint absorps 90% of the incident rays and then emits this as long wave radiation. The base of the collector was insulated with polyurethane foam to reduce the back loses due to conduction.

A plastic container was purchased as a standard part for the storage tank to reduce cost. The tank was so chosen to prevent corrosion which could lead to the blockage of the pipe channels.

The incubator is a rectangular box made of wood to reduce cost and to contribute to insulation. The top of the box is grooved for the cover to sit on so as to reduce heat leakage due to convection at the openings. Coiled round the inner part of the box are copper pipes of 13mm external diameters that supply hot water into the chamber to provide the needed heat to the eggs. The floor of the incubator is made spacious enough to contain 30 eggs and a bowl of water to regulate humidity. The side of the incubator was drilled to allow for the ventilation of the eggs.

Design Calculations
Flat plate collector

Evaluation of useful heat gain by collector Q_U

$$Q_U = A_C F_R R(\tau\alpha)(H - H_C) \qquad (9)$$

R = 1.083

$(\tau\alpha) = 0.78$

$F_R = 0.855$

$H_C = 17.3W/m^2$

and also the average daily radiation H for Abeokuta is taken as $20.44MJ/m^2/day = 5.67kWh/m^2/day$ according to (Olaleye, 2008)

$$Q_U = 4088W/m^2$$

Collector efficiency

$$\eta = \frac{Q_U}{A_C HR} \qquad (10)$$

$\eta = 65.56\%$ for $A_C = 1m^2$

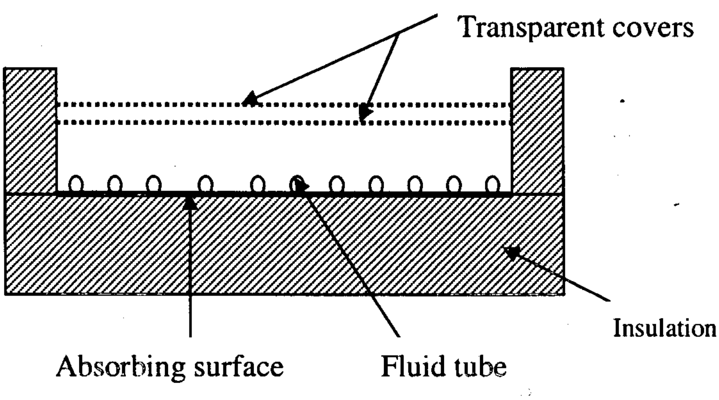
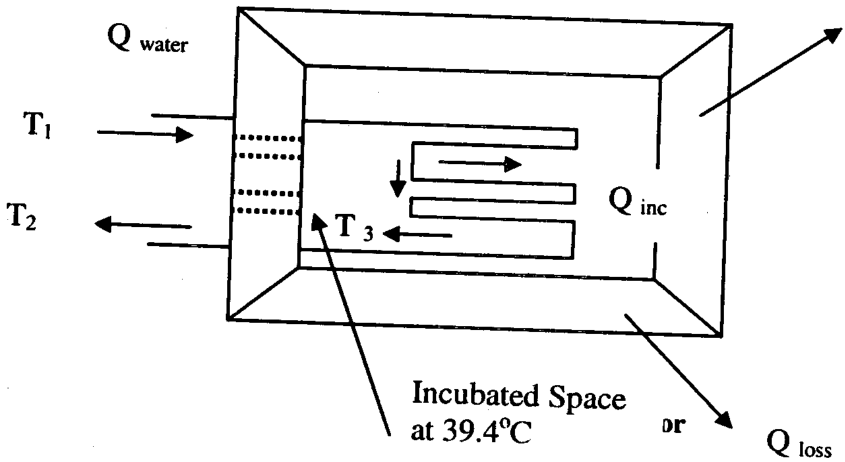


Fig. 3 Basic Flat Plate Solar Collector

The incubator

The appropriate incubator dimension was chosen to accommodate a crate of eggs (30 eggs), a thermom humidity-regulating device and the copper coils wound around the incubator. This area was conveniently c $45cm x 38cm$, and with a height of 20cm to conserve space.



Ventilation required

The required ventilating rate at chick emergence is $0.0275m^3/\min$. (Adewumi, 1998)
Calculating the area of ventilating ports

$Q = A_v V_{ch}$

Q = volumetric flow rate of air = $0.0275/60 = 0.000458m^3/s$ (11)

V = wind velocity = 0.09m/s

Circular cross-section for ports, $A_v = \pi D_v{}^2/4$

∴ total diameter required is 8cm

Heat load requirement

The total heat load requirement by the incubator is given by

$$Q_w = Q_{loss} + Q_v + Q_{inc.} \qquad (13)$$

For ambient air incubator volume = $0.0342m^3$

$$Q_{loss} = \frac{K_w A_s (T_3 - T_a)}{L} = 1.7W \qquad (14)$$

$$A_s = 0.494m^2$$

$$Q_v = \rho_s V_{ch} (\Delta T) \qquad (15)$$

$$\Delta T = 12^o C$$

$$Q_v = 0.007W$$

$$Q_{inc} = \rho V_a C_p T \qquad (16)$$

$$Q_{inc} = \rho V_a C_p (273 + 39.4)$$

$$= 13.87W$$

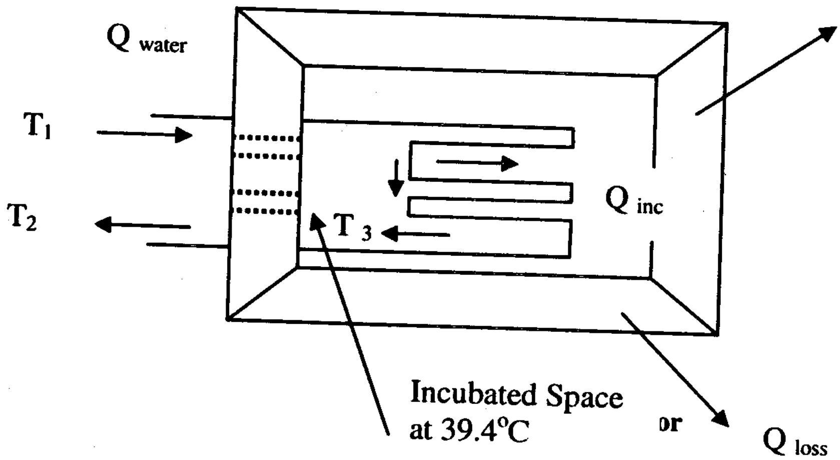
V_{inc}, incubator volume = $0.0342m^3$

$\Delta T = 12^o C$

$$Q_w = Q_{conv} + Q_{rad} \qquad (17)$$

The incubator

The appropriate incubator dimension was chosen to accommodate a crate of eggs (30 eggs), a thermometer, a humidity-regulating device and the copper coils wound around the incubator. This area was conveniently chosen $45cm x 38cm$, and with a height of 20cm to conserve space.



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V_{inc}, incubator volume = $0.0342m^3$

$\Delta T = 12^o C$

$$Q_w = Q_{conv} + Q_{rad} \quad (17)$$

$$Q_{conv} = hA_p(T_w - 39.4) = h\pi D_p L(T_w - 39.4) \quad (18)$$

$$Nu = c(Gr\Pr)^n \quad (19)$$

where Nu = Nusselt number
Gr = Grashof number
$\Pr$ = Prandtl number, c and n are constants

$$Gr = \frac{\left|g\beta(T_w - 39.4)D_p^3\right|}{v_a^2} \quad (20)$$

with $g = 9.8 m/s^2$,

$$\beta = \frac{1}{T_f} = \frac{1}{313}$$

$$v_a = 1.731x10^{-5} m^2/s, \Pr = 0.704$$

where, v_a = kinematic viscosity of air

$$Gr = 2.3x10^3$$

$$Ra = Grx\Pr \quad (21)$$

$$Ra = 1.6x10^3$$

$$Nu = \frac{hD_p}{K_a} = c(Ra)^n \quad (22)$$

with c taken as 0.675, and n = 0.058, (Olaleye, 2008)
K_a =conductivity of air = $0.0262W/m^oC$

$$Nu = 0.675(1.6x10^3)^{0.058} = 1.035$$

Let us consider equation (22),

$$h = \frac{K_a(Nu)}{D_p} = 2.1$$

$$Q_{conv} = \pi D_p Lh(\Delta T) \quad (23)$$

$$= 0.89L$$

$$Q_{rad} = \varepsilon\pi D_p L\sigma(T_w^4 - 313.4^4) \quad (24)$$

σ = Stefan boltzman's constant = $5.67x10^{-8}W/m^2K^4$

$\varepsilon = 0.9$, the copper pipe was painted black to increase its absorptivity

T_w is the temperature of the hot water at the inlet of the pipes, $323K$

$$\therefore Q_{rad} = 2.56L$$

$$Q_w = 0.89L + 2.56L = 3.45L$$

Q_w = 15.58W
$\therefore$ length of copper pipe required = 4.52m

Storage tank
The tank was assumed to supply for the remaining parts of the day without sunlight.
The number of hours without sunlight = $24 - 5.9 = 18.1hrs$

Suppose the storage tank will lose temperature from 50^oC to 40^oC, the total energy in joules available from the tank is given by

$MC_p(10) = 4190\,X\,10M$,

where for water, $C_p = 4190J/kgK$

The total Watts required from load = 15.58W
Therefore for the 18.1hr the amount of energy in Joules required by the load = 1.02MJ
Therefore the mass of water required to supply this load = 24.34kg
From the equation of energy balance on the tank,
rate of energy entering Q_U = rate of energy build up Q_s + rate of energy leaving Q_L.

$Q_s = MC_p(\Delta T) = 4088W$

$Q_u = 4088 + 15.48 = 4103.48W$

Therefore the area of collector required = $4103.48/4088 = 1.004m^2$

Construction
The solar incubator was constructed using locally available materials. Simple machining processes like drilling, milling, cutting, filing and joining were employed in the construction of the absorber and piping system. The casing was made of wood
The storage tank was purchased as a standard part and plastic was chosen to reduce corrosion in the tank which can block the water flow channels.

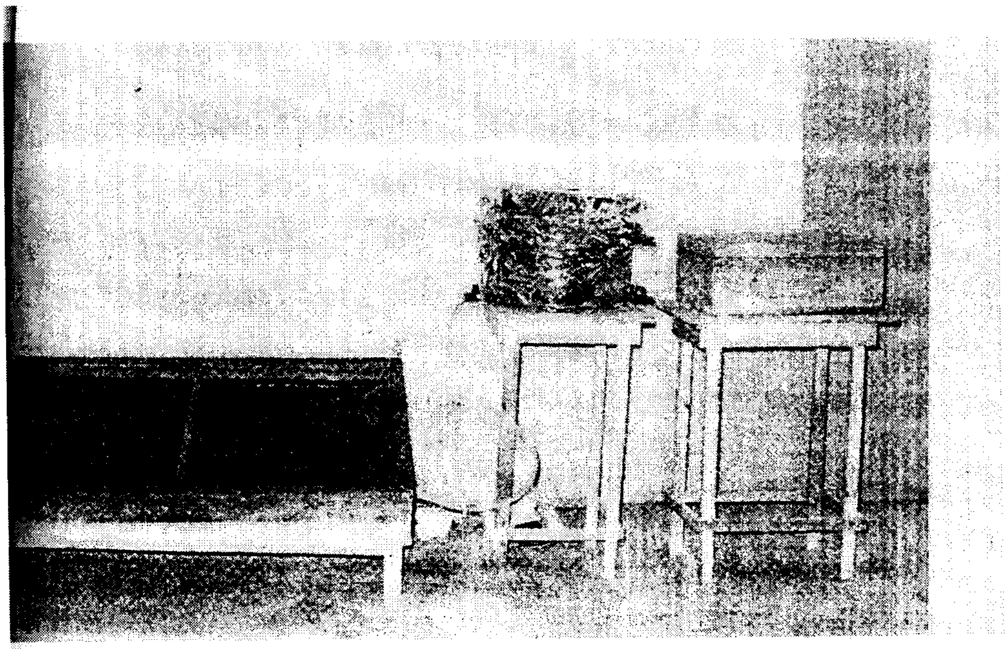

Fig. 5 Pictorial View of the Constructed Solar Incubator

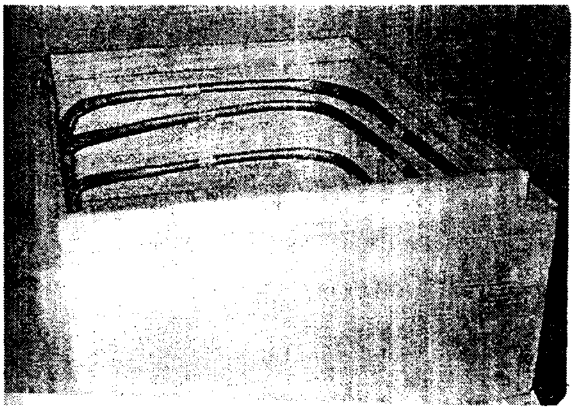

Fig. 6 Pictorial View of the Incubating Chamber showing the Heat Exchanger Coils

Conclusion

The foregoing exercise has demonstrated the possibility of incubation of eggs using solar energy. The prototype has established the possibility of using readily available solar energy to increase chicken production to satisfy masses protein needs.

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