CONSTRUCTION AND OPERATION OF A CYLINDRICAL SOLAR WATER HEATER

BY

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Dedicated to my Mum and Dad for their love, guardiance, sincerity and financial support throughout the duration of my course.

ABSTRACT

The project reviewed solar energy, its application and solar collectors.

The cylindrical solar energy collector has been designed, constructed and tested. The collector and storage efficiency have been calculated from measurement for the month of July. The investigation of some of the parameters gives value for the specular reflectance as 0.65; transmittance absorptance product as 0.88 and intercepting factor as 0.75. An absorber water temperature of 82.5°C was recorded. The storage tank efficiency has been obtained as 41% and a collector efficiency of 44.25%

Suggestion for further development on this work were given.

ACKNOWLEDGEMENT

I thank Almighty Allah for guiding me and making it possible for me to go this far in my educational endeavour. I thank my parent who I owe a great debt to for sponsoring me. me My gratitude also goes to my supervisor, Mr. Y.M. Ngalla, who willingly devoted his precious time to supervise this work.

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GLOSSARY SYMBOLS

SYMBOLS	MEANING	UNIT
σ	Stefan-Boltzman Constant	w/m^2k^4
η	Efficiency	-
ε	Emissivity	-
ρ	Specular reflectance	-
γ	Intercepting Factor	-
π	Pie	-
a	absorbtivity	
$\dot{m}$	Mass flow rate	Kg/s
K	Thermal conductivity	J/mk
T_a	Ambient temperature	$^oC/^ok$
C_p	Specific Heat capacity	KJ/Kg^oC
S	Flux absorbed	w/m^2
U_l	Heat loss	$w/m^{2o}C$
T_h	Temperature of heater in tank	$^oC/^ok$
T_c	Temperature of absorber fluid	$^oC/^ok$
T_g	Temperature of glass	$^oC/^ok$
C	Concentration ratio	-
τ	Transmittance absorptance product	-

CHAPTER ONE

INTRODUCTION

1.1 SOLAR ENERGY

Over millions of years plants covering the earth convert energy from the sun in the presence of atmospheric carbon (IV) oxide to food in a process known as photosynthesis. Some of these plants which are buried deep in the earth decompose to produce coal, oil and natural gas. During the past decades man has found many valuable uses of this complex chemical substance, producing from them plastic, textile and other products of petro-chemical industry. Each decade sees increasing use of these products.

However, man has found another use of these valuable chemical from the earth, a use other than the creation of products that add to our standard of living, but to burn them. To burn them in ever increasing quantities to power our machine and provides heat. They are burnt at such incredible rate that in a few decades the world reserve of of natural gas would be depleted.

It is in recognition of this fact that an alternative has to be sought and solar energy happens to be the answer. The sun produces 4×10^{26} joules of energy per second and the earth receives only 5×10^{24} joules a year which is 30,000 times the energy requirement at the present time. In our society there is great demand of energy which at present is hardly met by burning gas, oil, coal or use of electricity through hydro or thermal processes.

A considerable fraction of this energy demand could be met by utilising the abundant supply of solar energy the country is blessed with.

1.2 WHAT IS SOLAR ENERGY

Solar energy is the energy that comes from the sun which is electromagnetic in nature covering all wave lengths. The sun is a hot gasious body with a surface temperature of 6×10^3k. It could be said to be a big continuous fusion reactor which is supported by gravitational force. It is believed that the sun's energy arises from the proton-proton chain reaction. This reaction is a thermonuclear reaction whereby hydrogen atoms are transformed into heliumwith with enormous amount of energy been released in the process. This process is initiated by a reaction between two protons with the end result of a helium atom formed and two protons to initiate another chain reaction. The reaction could be written as

$$^{1}H + {}^{1}H \longrightarrow {}^{2}H + e^{+} + \nu$$

$$^{2}H + {}^{1}H \longrightarrow {}^{3}He + \gamma$$

$$^{3}He + {}^{3}H \longrightarrow {}^{4}He + {}^{1}H + {}^{1}H$$

The energy so formed occurs in the interior of the sun, as it is this region which could sustain such reaction. The energy produced is carried to the surface to be radiated into space. Most of the solar radiation is confined with in in wavelength of 0.38 and 0.78 m.

1.3 AVAILABILITY OF SOLAR ENERGY

The availability of solar energy over the earth surface is not uniform. It is more abundant in some areas than others. The sun's shinest region on the earth lies between latitude 20 - 30'N and South of the equator. The amount of solar intensity intercepted by the earth on a unit area per unit time at its mean distance from the sun is called solar constant which has a value of 135Wm^{-2}. This value is not that constant as it varies. The variation is due to the eccentricity of the earth orbit such that the distance between the earth and the sun varies by ± 3%.

Certain factors affect the availability of solar energy on the earth. These are:

a. Atmospheric condition

b. Geographic location

c. Time-day and year

Atmospheric condtion determines to a great deal the amount of solar radiation reaching the earth's surface. As solar radiation transverse the atmosphere, several complex physical and chemical effect occurs which affect greatly the intensity and spectral distribution of solar radiation on the earth surface. The principal mechanism causing atmospheric alternuation of sola radiation is atmospheric scattering and atmospheric absorption including reflection. Atmospheric scattering has a consequence of separating the solar radiation into direct and diffuse components.

There are several atmospheric constituents which absorb incoming solar radiation. The ozone layer absorbs nearly all the ultra-violet radiation. Water vapour absorbs solar radiation in the infra-red region, hence the spectral distribution shows several pronounced dip and peak in the infra-red region. Variation in atmospheric water content produces 5 - 20% variation in intensity of direct solar radiation on the earth surface.

The amount of water vapour in the atmosphere depends upon climatic type, season and local altitude. Dry arid region of the earth receives more solar energy than the wet regions of the earth. This is due to the amount of water content and cloudiness. Cloud frequently reduces incoming radiation up to 9 90% by single and multiple scattering thus reflecting that amount into space. Scattering varies invesely as the fourth power of wavelength.

The significant seasonal variation in solar flux per unit area on the earth surface is due to the maximum tilt of the earth's axis (23.5°) relative to the plane of its orbit about the sun. For both vernal and autumnal equinox puring the daily rotation of the earth, suns rays perpendicular to the earth surface at the equator illuminate both the northern and southern hemisphere equally. Summer in the South hemisphere corresponds to the Sourthern hemisphere being tilted towards the sun and winter the converse. The sun's ray is normally incident on the earth's surface at the following latitude and time:

23.5°N - 21st June

0° - 21st March/21st September

23.5° - 21st December.

The net solar energy reaching the earth is depicted by the solar spectrum, fig. 1.1.

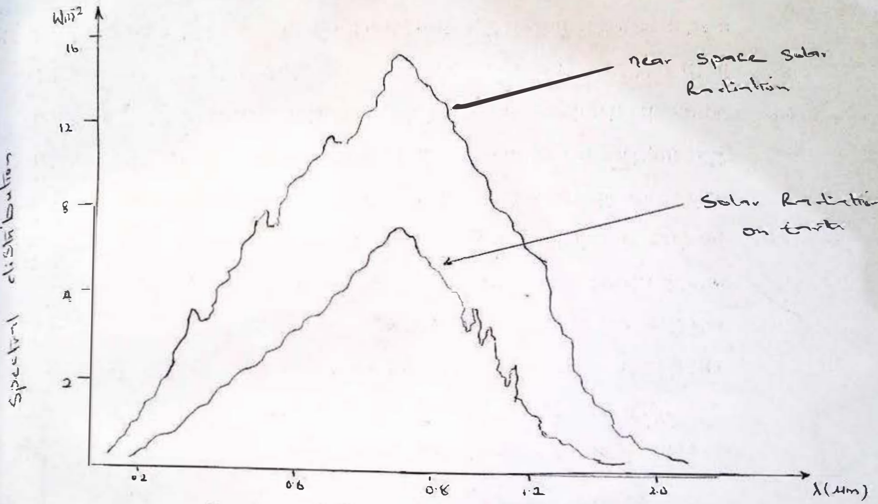

fig 1.1 Solar Spectrum

The distribution of solar radiation with wavelength known as extraterrestrial solar spectrum shows the various component of solar radiation in different wavelength regions depicted in fig. 1.2 45% of the energy is in the visible region while 50% in the infra-red region. The solar energy intensity peaks at 0.6 microns with small fraction in the ultra violet region.

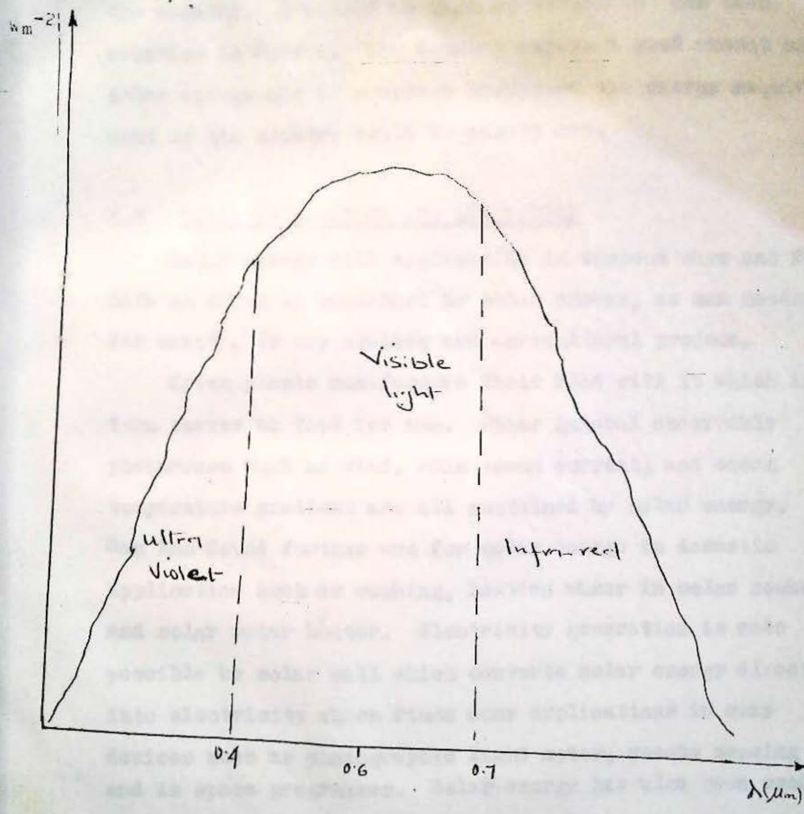

Fig. 1.? Energy region According to wavelength in Solar Spectrum

1.4 NIGERIA'S SOLAR POTENTIAL

Nigeria lies between 4^{o} and $14^{o}N$ of the equator and has daylight or sunshine hour of not less than 11 hours per day. Radiation upto 5500al/cm^2 has been recorded within the country. A record as high as 5000al/cm^2 has been recorded in Bauchi. The country enjoys a good amount of solar energy and if properly harnessed the energy requirement of the country would be easily met.

1.5 USES, APPLICATION AND LIMITATION

Solar energy find application in various ways and fields. Life on earth is sustained by solar energy, as man needs it for warmth, to dry clothes and agricultural produce.

Green plants manufacture their food with it which in turn serves as food for man. Other natural observable phenomenon such as wind, rain ocean current, and ocean temperature gradient are all sustained by solar energy. Man has found further use for solar energy in domestic application such as cooking, heating water in solar cooker and solar water heater. Electricity generation is made possible by solar call which converts solar energy directly into electricity which finds many applications in many devices such as photographic light meter, remote sensing and is space programmes. Solar energy has also been used in distilling water., in irrigating farm land by solar lift pump. Solar energy has also been used in refrigeration, cooling and space heating which has found various uses in the tropic and temperate regions.

It has also found uses in medicine, avaition, telecommunication, power generation and space sciences. Above all solar energy is inexhaustible and pollution-free.

In spite of the numerous fields it has found uses and its overwhelming advantage over the normal conventional fuel, it is still being hindered by certain factors which makes solar energy as an alternative to normal conventional fuel expensive.

The inherent natural problems of collecting solar radiation and storage, lead to complicated devices which when applied on a large scale makes the cost exorbitant. Geographical factor is another problem as climatic condition is not uniform all over the earth, hence the question of time weather or season comes in place.

Though for now solar energy collection and storage is expensive, it should not be discouraged as solar energy is the only lasting solution to our energy problem if the proper technology is developed to harness it.

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CHAPTER TWO

SOLAR COLLECTORS

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2.1 INTRODUCTION

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c. solar cell.

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2.1 FLAT PLATE COLLECTOR

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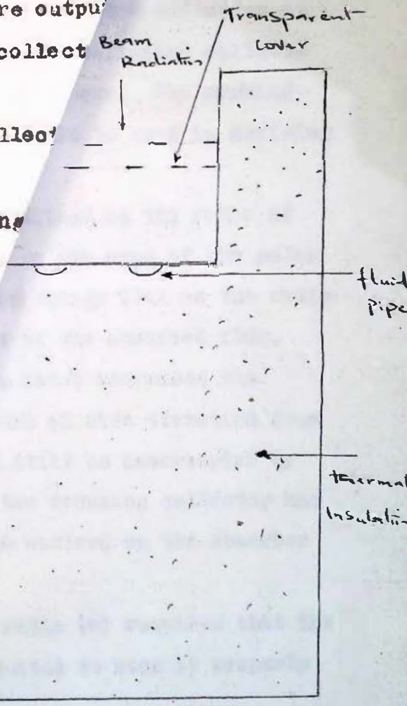

plate Solar Collector

CHAPTER TWO

SOLAR COLLECTORS

2.1 INTRODUCTION

A solar collector is any device which absorbs solar energy. A black body is a good absorber of solar energy. The choice of any collector is determined by what it is to be used for and what temperature output is expected. There are principally 3 kinds of collectors:

a. flat plate collector;

b. concentrating or focusing collector and

c. solar cell.

It is known that concentrating collector has been used to achieve very high temperatures while the flat plate which has extensively been used, is used for moderate temperature heating. The flat plate and concentrating collector both convert solar energy into radiant energy which is then used in other forms while the solar cell converts solar energy directly into electricity.

2.1 FLAT PLATE COLLECTOR

The flat plate collector is a blackened flat surface exposed to the sun without any optical device to enhance the solar energy flux. The area absorbing solar radiation is the area intercepting it. The flat plate is usually made of material with good thermal conductivity. A pipe attached underneath the absorbing surface carries the working fluid.

Heat energy is obtained by heat exchange between the plate and the fluid flowing through the pipes.

The flat plate has the advantage of being able to use both the diffuse and beam component of solar radiation and does not require much tracking of the sun as it moves across the sky. It is easy to construct and handle. Fig.2 Fig. 2.0 shows the flat plate collector.

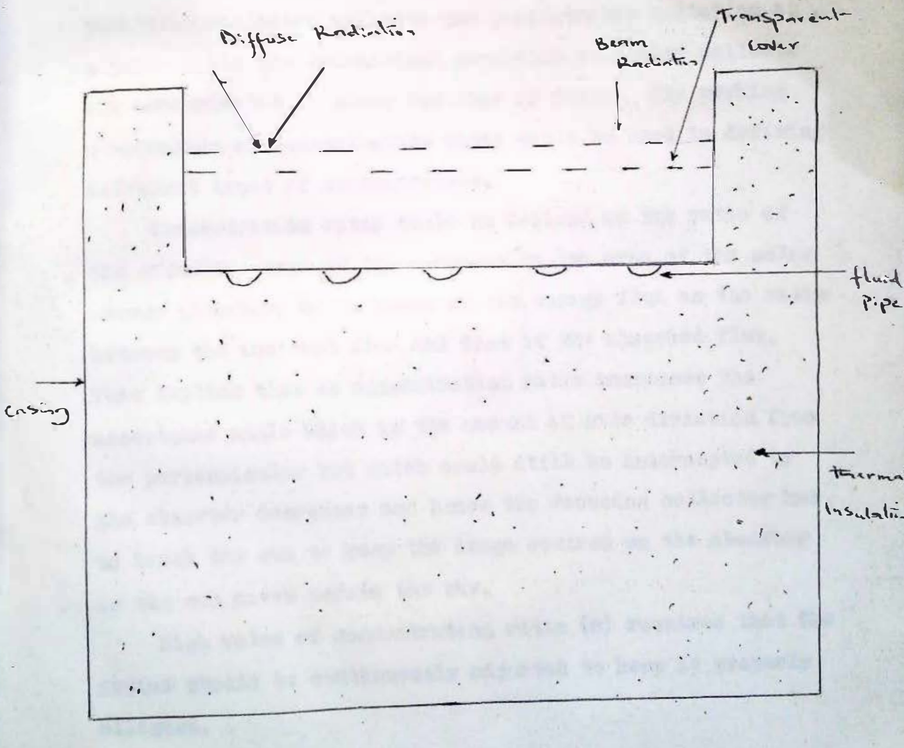

fig 2.1 flat plate solar collector

2. 2 CONCENTRATING COLLECTOR

Concentrating collector utilises optical system in enhancing solar energy flux. Basically there are two kinds: the reflector which utilises mirrors and other material with reflecting properties and refractor which utilises freshal lenses. The reflecting surface used in concentrating radiation, on an energy absorbing surface could be cylindrical parabolic or spherical parabolic. The spherical parabolic collector collects and concentrates radiation at a point while the cylindrical parabolic collector collects and concentrates it along the line of focus. The working temperature or concentration ratio could be used in defining different types of concentrators.

Concentration ratio could be defined as the ratio of the effective area of the aparture to the area of the solar energy absorber, or in terms of the energy flux as the ratio between the incident flux and that of the absorbed flux. This implies that as concentration ratio increases the acceptance angle which is the amount of side diviation from the perpendicular but which could still be intercepted by the absorber decreases and hence the focusing collector has to track the sun to keep the image centred on the absorber as the sun moves across the sky.

High value of concentration ratio (c) requires that the device should be continuously adjusted to keep it properly alligned.

The concentration ratio could be written mathematically as

$$C = \frac{\sin\phi}{\sin\theta_c}$$

Where ϕ = rim angle and θ_c the acceptance angle.

One consequence of the above definition is that a collector with a small acceptance angle and small absorbing area. would have high concentration ratio, hence high efficiency due to small thermal loss from small absorbing area. This is why spherical concentrating collectors which concentrate at a point have been able to achieve a very high temperature output since the energy intensity at the focus could be extremely high. Fig. 2.2 and 2.3 show the spherical and parabolic cylindrical collectors.

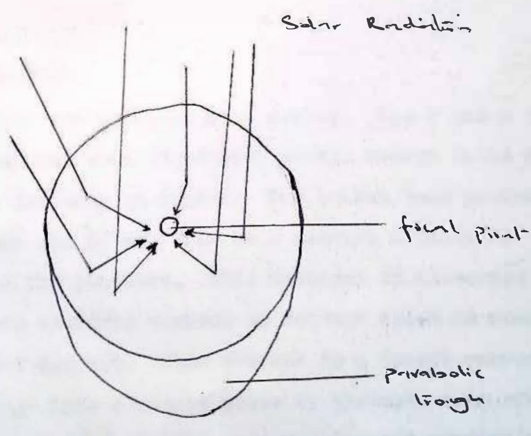

Fig 2.2 Spherical Concentrating Collector

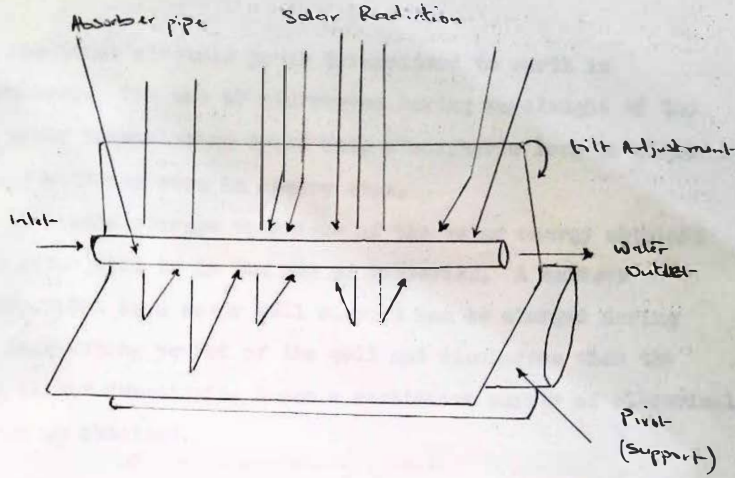

Fig 2.3 Cylindrical Concentrating collector

2.4 SOLAR CELL

Solar cell are simiconductor devies. The P and n type are in contact and when light with enough energy falls on the junction the bond is broken. The broken bond produces free electrons and holes. The hole carries a positive charge acsoss the junction. This movement of electross and holes produces electric current or voltage which is measured by an external circuit. This process is a direct conversion of solar energy into electric power by photoelectric effect. Silicon and germanium are the most widely used semiconductors.

A silicon photocell is a photovoltaic cell which behaves as a normal p-n junction in the absence of light. To overcome problems associated with clouds or day-night cycle a photovoltaic device can be arranged in space and the resultant electric power transmitted to earth in microwaves. The use of microwaves having wavelenght of tem for power transmission would keep atmospheric loss to about 6% and moderate even in severe stom.

A simple storage technique of the solar energy obtained from solar cell is in the use of batteries. A battery incorporated in a solar cell circuit can be charged during the functioning period of the cell and discharges when the cell is not functioning hence a continuous supply of electrical energy is obtained.

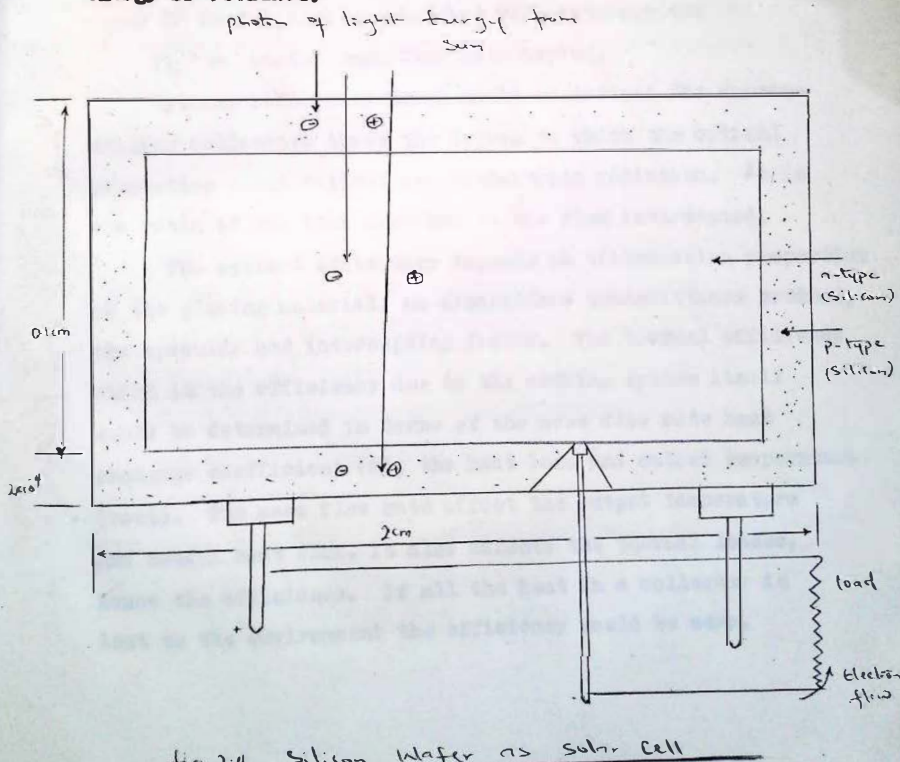

fig 2.4 Silicon Wafer as Solar Cell

2.5 EFFICIENCY OF SOLAR COLLECTORS

The performance of any collector can be discribed using two coefficients:

a. Optical coefficient which discribes the degree to which solar radiation is collected,

b. The heat lost to the environment

Heat loss to the environment increases with collector temperature, hence collector with small overall heat loss would have a higher efficiency value than one with a high value of heat loss. Efficiency could be defined as the ratio of useful work to absorbed flux intercepted.

η = useful work/flux intercepted.

Optical efficiency which could be defined for concentrating collectors shows the degree to which the optical properties could reflect and concentrate radiation. It is the ratio of the flux absorbed to the flux intercepted.

The optical efficiency depends on transmission properties of the glazing material, on absorbtance transmittance product, the specular and intercepting factor. The thermal efficiency which is the efficiency due to the working system itself could be determined in terms of the mass flow rate heat exchange coefficient (H), the heat loss and output temperature (Tout). The mass flow rate affect the output temperature and useful heat flux. It also affects the thermal losses, hence the efficiency. If all the heat in a collector is lost to the environment the efficiency would be zero.

CHAPTER THREE

THEORY OF THE CYLINDRICAL CONCENTRATING COLLECTOR

3.1 INTRODUCTION

In any solar collection device, the principle usually implored is to expose a dark surface to solar radiation, so that radiation is absorbed. When optical system is utilized to collect or enhance the intensity of solar radiation on the energy absorbing surface, the device is called a concentrating collector.

Every system for conversing of solar energy which are practically energy at short wavelength to thermal energy or longwave length energy should include:

a. Solar collecting surface

b. thermal storage

c. heat transfer fluid which transfers the extracted energy from the collector to the thermal storage. Some heat transfer fluid are: air, water, oil and some organ fluid. Water is the most suitable transfer fluid but limited by its boiling point.

The temperature achieved for a focusing collector is usually high due to concentration of solar energy on a small area. The smaller the area, the higher the energy vlus and the higher the temperature.

3.2 CYLINDRICAL PARABOLIC CONCENTRATING COLLECTOR

There are different kinds of configuration of focusing collectors which allow new set of design parameters. One of which is the cylindrical collector. The cylindrical parabolic collector focuses radiation onto the axis where it is absorbed. It is also known as line focusing collector. It is made up of:

a) Parabolic concentrator

b) Absorber material and

c) Glazing material. Fig 3.1 shows a typical cylindrical parabolic collector.

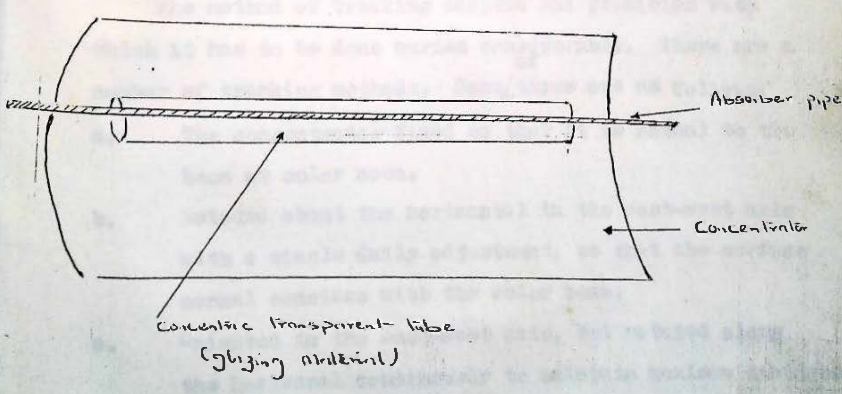

Fig. 3.1 Cylindrical Solar Collector

3.3 THE CONCENTRATOR AND TRACKING METHODS

In the cylindrical parabolic collector, the parabolic concentrator is the aperture open to solar radiation, which reflects and concentrates solar radiation along a line focus of the cylindrical parabola. An absorbing material placed along this focus collects this radiation in form of heat and transfers it to a working fluid.

The cylindrical concentrating collector like other concentrating collectors utilizes only the beam compound of solar radiation, which implies that it has to tract the sun or the variation in the incidence angle between the direction of solar beam and the normal to the plane of the collector, wild severely limits the time when the collector can direct solar radiation on the absorber.

The method of tracking adopted and precision with which it has to be done varies considerably. There are a number of tracking methods. Some of these are as follows:

a. The concentrator fixed so that it is normal to the beam at solar noon.

b. Rotated about the horizontal in the east-west axis with a single daily adjustment, so that the surface normal concides with the solar beam.

c. Oriented in the east-west axis, but rotated along the horizonal continously to maintain maximum incidence.

d. Oriented in the north-sourt axis, but rotated about the horizontal continuously to maintain maximum incidence.

e. Oriented in the North-Sourth axis but rotated about the exis parallel to the earth's axis, with continuous adjustment to maintain maximum incidence.

f. Rotated about the axis continuously to allow the surface normal to concides with the solar beam at all times.

Tracking could be done electro-mechanically by the use of photosensitive devices or manually.

The concentrator is of great importance to the performance of the collector, as it determines the optical loss factor, it also determines the amount of solar intensity that would reach the absorber.
Irregularities in the reflector construction results in spreading and distortortion of the flux, with the consequence of having less concentration of solar intensity in the focal zone.

The optical loss is the product of the specular reflectance, transmittance absorbtance product and the intercepting factor.

3.3.1 SPECULAR REFLECTANCE

The specular reflectance is a function of the nature of the reflecting surface. It is the fraction of incident beam to the collinminated incident beam which is reflected, such that the angle between them differ by a factor of π, which implies that the angle of incidence is equal to the angle of reflection. Mathematically specular reflectance (P) is given as

$$P = \frac{AS}{AI} \quad (3.1)$$

Where DS = reflected radiation beam

DI = incident radiation beam

It is observed that polished surface have low value to emissivity and high value of reflectance, while rough and unpolished surfaces, have high value of emissivity and low value of reflectance. The mathematical relation between emissivity (ε) and reflectance is given by

$$P = 1 - \varepsilon \quad \text{------------} \quad (3.2)$$

Efficiency and outlet fluid temperature increases with specular reflectance.

3.3.2 INTERCEPTING FACTOR

The intercepting factor represents the fraction of specular reflected radiation that is intercepted by the energy absorbing surface. It is a strong function of the properties of the reflector and the receiver relative position to the concentrator in intercepting image. For cylindrical system, the intercepting factor could be calculated mathematically from the equation.

$$\gamma = \frac{2}{\sqrt{\pi}} \int_0^{h(W/w)} e^{-h^2 (w/W)^2} \, d\left(\frac{hw}{W}\right) \quad \text{------} \quad (3.3)$$

where

γ = Intercepting factor

W = half width of concentrator

w = Distance from centre

h = normal flux distribution coefficient.

If the normal flux distribution coefficient and the receiver width is known, different falues of intercepting factor could be obtained for different geometric shapes. The intercepting factor strongly affects efficiency. The

The intercepting factor also determines the amount of thermal loss. The smaller the area, the smaller the thermal loss, but the larger the optical loss because of reduced intercepting factor.

3.3.3 THE TRANSMITTANCE-ABSORPTANCE PRODUCT

The transmittance-absorptance product is another factor which contributes to the optical loss factor. It plays the same role as in flat plate collector, but varies considerably for concentrating collector. Its values may be higher or lower due to certain parameter which are dependence on the angle of incidence of solar radiation on the cover and absorbing material and properties of the glazing material.

3.4 GLAZING:

A concentric transparent material enclosing the absorber, which could be glass, can be used for glazing.
The transparent concentric material minimizes the amount or rate of heat loss from the absorber to the surrounding. It allows radiation at shortwavelength 0.3 to 0.5 micsons to pass through but opaque to longwavelength radiation, radiation with wavelength exceeding 20 microns.

3.5 THE ABSORBER

The absorber is relatively an important piece in concentrating collectors. The size of the receiver and its position relative to the relector is of great importance to the performance of the collector.

It determines the amount of thermal loss and to some extent the optical loss from the collector.

The receiver size is dependent upon the sun's angular width, the magnitide of tracking, slope error and irregularities of reflecting surface. It is tin the receiver that heat exchange to the working fluid occurs.

It is often made of material of good thermal conductivity on which has been deposited a surface coating which is absorbent to solar radiation. The simplest method consist of painting the material black. A good coating of paint gives the surface an absorption coefficient of about 0.8 to 0.9.

To reduce loss from the collector and increase efficiency, the absorber surface can be coated with a selective coating which has high absorptivity for radiation of wavelength about 2 microns and smallest possible emissivity for infra-red radiation.

3.6 HEAT LOSS AND HEAT TRANSFER COEFFICIENTS

In calculating the thermal loss in concentrating collectors, the same principle used in calculating the heat loss in flat plate is used. It is assumed that, the energy which the sun emit is uniform at all times, and that the colleotor fluid is a non-radiating medium. The temperature of the receiver and envelope is circumfrentically uniform, the mass flow rate is constant, and the tempoerature gradient through the thickness of the wall of receiver and envelope can be neglected.

The radiative and convective heat loss from glass to surrounding could be expressed as

$$Q_{loss\ glass} = h_g A_p (T_g - T_a) + (\sigma \varepsilon_g f_{g_a})(T_g^4 - T_a^4) \quad \text{------} (3.4)$$

where

h_g = convective heat transfer coefficient at outside envelope surface of glass ($w/m^{2\circ}c$)

A_p = outside surface of glass envelope (m^2)

ε_g = Emissivity of glass

f_{gs} = radiative shape factor

T_g and T_a = glass and ambient temperature respectively

$$h_g = \frac{KNu}{L} \quad \text{------} (3.3)$$

where

K = thermal conductivity

L = length

Nu = the Nussett number.

The convective and radiative heat loss from receiver to glass could be expressed as

$$Q_{loss\ receiver} = \frac{\sigma A_t (T_t^4 - T_g^4)}{\left(\frac{1}{\varepsilon t} + \left(\frac{D_t}{D_g}\right)\left(\frac{1}{\varepsilon g} - 1\right)\right)} + \frac{2\pi K}{D_o} \frac{(T_t - T_g)}{\ln\left(\frac{D_t}{D_g}\right)}$$

where

εA_t = area of receiver

ε_t = emissivity of receiver

K_e = effective thermal conductivity

T_t = temperature of receiver

D_t and D_g = diameter of receiver and glass respectively

If the heat transfer from fluid is taken into account, the overall, heat transfer from fluid to surrounding, u_o

taking account of the heat loss from the outer surface tube is given as

$$U_o = \left(U_1 + \frac{h_i D_i}{D_o} + \frac{2k}{D_o \ln \frac{D_o}{D_i}}\right) \quad \text{------(3.6)}$$

where

U_1 = heat loss coefficient from outside surface of tube

h_i = heat transfer inside tube

K = thermal conductivity of tube

D_o & D_i = are inside and outside diameter of tube.

Energy balance equation is given as

$$qu = \frac{A_a}{L} H_b R_b \, T\alpha Y - \tau D_o U_1 (T_t - T_{in}) \quad \text{------(3.7)}$$

If the heat loss in the energy balance equation is solved for, and eliminating the receiver temperature, the useful heat transfer to the working fluid could be written as

$$qu = \frac{F^1 A_a}{L} \left(S - \frac{A_t}{A_a} U_1 (T_f - T_a)\right) \quad \text{------(3.8)}$$

T_f = fluid temperature

F^1 = collector efficiency factor. It gives the ratio of heat loss from the fluid to ambient to the heat loss from the collector system.

$S = H_b R_b \, p \, T\alpha Y.$

where

H_b = beam component of incident solar radiation

R_b = ratio of beam radiation on reflector aperture to that on any other surface

$pT\alpha Y$ = have their usual notation.

This useful energy transfer to the working fluid, could also be expressed in term of the mass flow rate ($\dot{m}$), heat capacity and temperature difference as

$$qu = \dot{m}cp\,(T_t - T_f) \quad\text{———————— (3.9)}$$

Combining (3.8) and (3.9) and integrating to solve for the temperature, imposing the condition that at x = o in the receiver, Tf = inlet fluid temperature, and $T_f = T_{out}$ at x = L. The length of the receiver gives the useful heat gain as:

$$qu = \dot{m}cp\,\left(\frac{S}{U_1} + (T_a - T_f)\right)\left(1 - \text{Exp}\ \frac{f^1 \pi D_o H}{\dot{m}cp}\right) \quad\text{——— (4.0)}$$

$$H = U_{1L}.$$

This gives the heat removal factor (FR) as

$$FR = \frac{\dot{m}cp}{A_t U_1}\left(1 - \text{Exp}\ - f^1 \frac{\pi D_o H}{\dot{m}cp}\right) \quad\text{———— (4.1)}$$

3.7 THE EFFICIENCY OF THE CYLINDRICAL COLLECTOR

The performance of a solar collector is determined by the rate, at which it is able to convert incident radiation into useful emergy with time. Efficiency could be defined as the ratio of useful heat gain to incident flux intercepted by the collector area. Which could be expressed as

$$\eta = \frac{\text{useful heat gain}}{\text{incident flux}}$$

The useful heat gain is the difference between the incident flux and the heat loss.

$$Q_{incident} - Q_{loss} = Q_{absorbed}.$$

$$\therefore \eta = \frac{Q_{incident} - Q_{loss}}{Q_{incident}} = \frac{Q_{absorbed}}{Q_{incident}}$$

Q_{loss} is a function or property of the system parameters, such as temperature, flow rate, heat exchange coefficient which determine to a great deal the efficiency of heat exchange to the working fluid.

CHAPTER FOUR

DESIGN AND CONSTRUCTION OF THE SOLAR WATER HEATER

4.0 INTRODUCTION

In this design most materials were improvised during the construction, by using materials available. Thus, in view of the limitations of availability of material cost, the approach adopted was more practically oriented.

The solar water heater consists of three main units which are:

a. the concentrator which collects and reflects solar radiation onto the receiver.

b. the absorber where conversion of solar energy to thermal takes place and

c. the storage unit which acts as the distributor of the working fluid and at the sametime stores the thermic fluid.

4.1 GLAZING AND ABSORBER MATERIAL

The abosorber was made of mild stell tube, of inner diameter 1cm, outer diameter 1.2cm and length 1.27m. Painted black with non-glossy black paint, so as to be able to extract solar radiant energy

The concentric glass cover, was that of a flourescent glass tube of length 1.2m, opened at both ends and washed clean to be transparent to solar radiation.

4.3 THE CONCENTRATOR

The concentrator was constructed out of tin sheets of thickness 0.41mm, length 1.27m and width 0.65m. Figure 4.1(a) and (b) shows the construction of the trough and arrangement

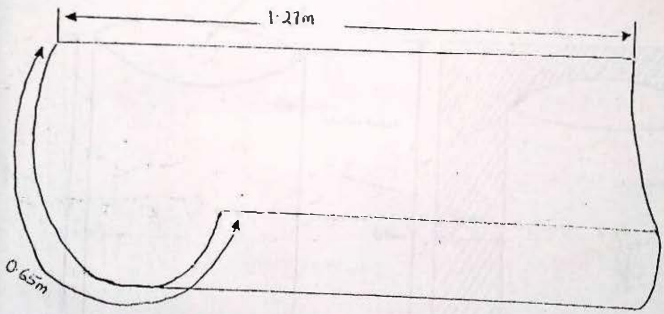

Fig.4.1a The Concentrating Cylindrical trough

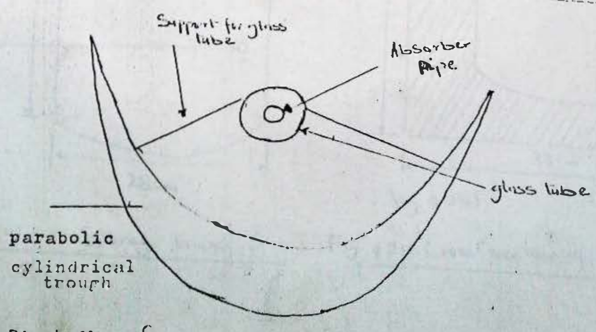

Fig.4.1b Cross-section of the cylindrical collector

4.4 THE STORAGE TANK

The storage tank is cylindrical, with a capacity of 41 litres. The tank was insulated with foam 5cm thick, to prevent the storage tank from losing heat, To further prevent heat loss - shining foil was wrapped round over the foam to reflect unwanted heat. Fig 4.2 shows the dimensions of the tank and insulation.

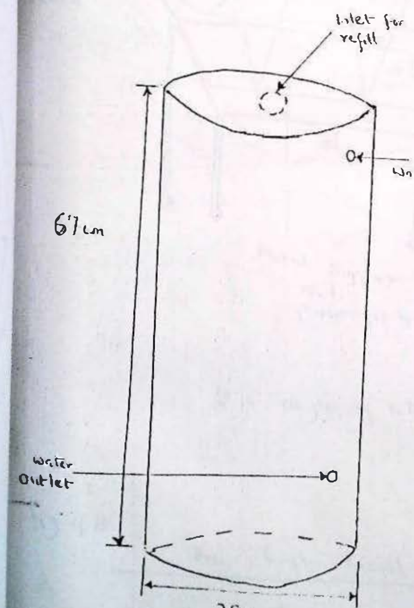

Fig 4.2(a) Storage tank

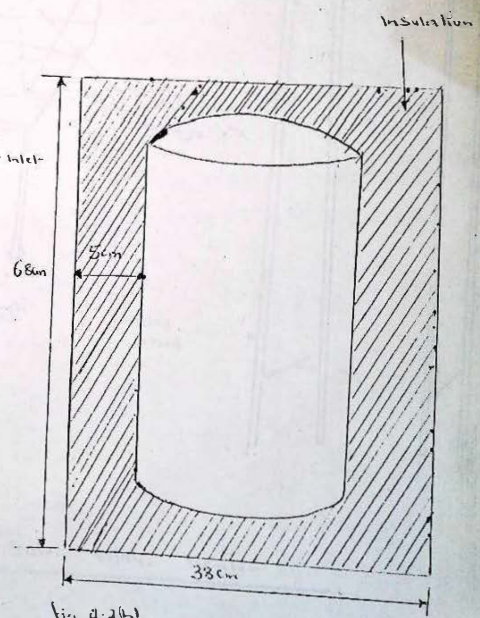

fig 4.2(b)

Fig. 4.2b. Cross-section of storage tank

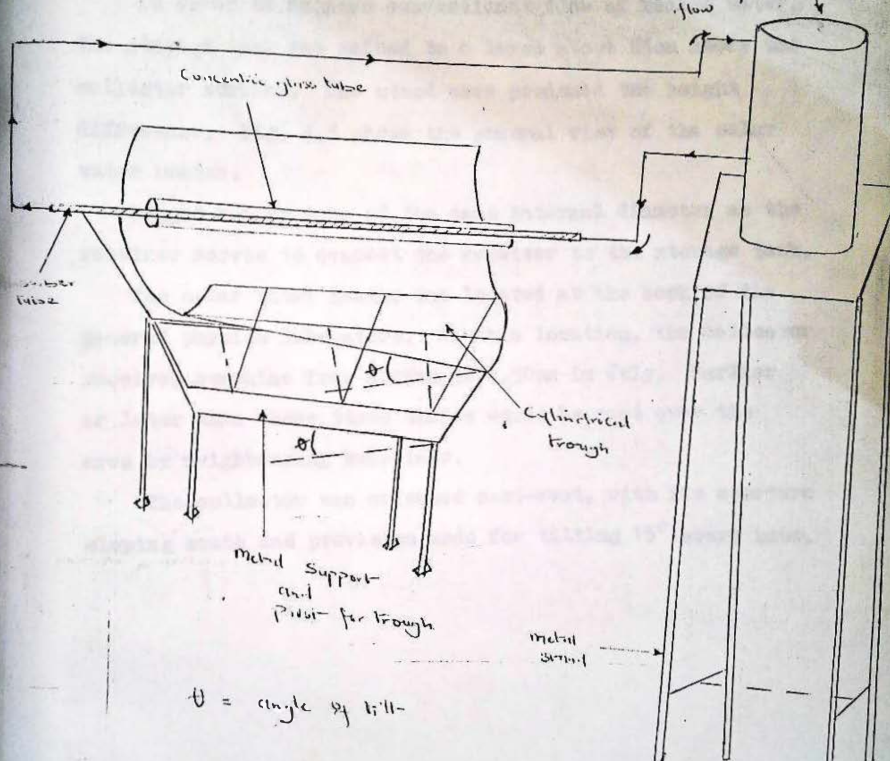

Fig. 4.3

The Cylindrical Solar Water heater

4.5 THE CYLINDRICAL SOLAR WATER HEATER

Heat was drawn from the system by water flowing through the receiving tube to the tank.

In order to achieve convectional flow of heated water, the storage tank was raised to a level about 65cm above the collector surface. The stand used produced the height difference. Fig. 4.3 shows the general view of the solar water heater.

Lagged rubber tube of the same internal diameter as the receiver serves to connect the receiver to the storage tank.

The solar water heater was located at the back of the general physics laboratory. At this location, the collector receives sunshine from 8.25am to 4.30pm in July. Earlier or later than these times shadow would be cast over the area by neighbouring buildings.

The collector was oriented east-west, with its aperture sloping south and provision made for tilting 15° every hour.

4.6 SUMMARY OF THE DIMENSIONS OF MATERIALS

1. Surface area of cylindrical trough = $(1.27 x 0.65) m^2$
   = $(.813 m^2)$
2. Length of absorbing tube = 1.27m
3. Length of concentric cover = 1.2m
4. Length of connecting tube = 4.05m
5. Volume of storage tank = 4! litres
6. Internal diameter of absorbing tube = 1cm
7. Internal diameter of concentric cover = 2.3cm
8. External diameter of absorbing tube = 1.2cm
9. External diameter of concentric cover = 3.8cm
10. Thickness of insulating material = 5cm

CHAPTER FIVE

MEASUREMENTS AND RESULTS

5.1 MEASUREMENTS

The measurements carried out in this experiment were:-

a. The temperature of water in the storage tank
b. The temperature of the absorber fluid and
c. The ambient temperature.

The temperature of water in the storage tank was measured with a mercury thermometer. The temperature of the absorber fluid, is the temperature of water tapped from the outlet of the absorber pipe. This temperature was measured by making a disconnection at the outlet of the abosorber pipe and tapping some into a flask. The ambient temperature is the temperature of the surrounding at the site.

Temperature readings and their corresponding incident radiant flux for the month of July are presented in tables 1 and 2. In each day in table one, the first row gives the ambient temperature, Ta, the second row gives the temperature water in tank, Tn, and the third row gives the temperature of the absorber fluid, To.

5.2 EFFICIENCY OF STORAGE TANK

The function of the storage tank is to keep the collected energy, so that it may be used at a later time. It is useful to calculate for the system the traction of heat retained by the storage. For this the difference in heat gain for the storage at its maximum temperature and it minimum which are proportional to temperature were used.

These temperature were obtained from the graph of fig. 5.1.

Maximum tank temperature Tn max = 29°C

Minimum tank temperature Tn min = 26.5°C

Minimum ambient temperature Ta min = 24.75°C

Percentage heat retained

$$\eta = \frac{T_{nmin} - T_{min}}{T_{nmax} - T_{amin}} \%$$

$$\frac{26.5 - 24.75}{29 - 24.75} \% = 41\%$$

This is the efficiency of the storage tank.

5.3 COLLECTOR EFFICIENCY

To calculate the efficiency of the collector, we need to know the amount of energy which the absorber pipe gains. Assuming solar constant remains the same for this time of

Table 1: Temperature Reading

H	7	8	9	10	11	12	13	14	15	16
15th										
Ta	24.5	26.0	27.0	29.0	31.5	33.0	35.0	32.0	31.0	30.0
Tn	30.0	29.5	29.0	28.5	28.0	27.5	26.0	26.0	26.5	27.0
Tc	27.0	35.0	40.0	56.0	71.5	74.0	82.5	76.0	56.0	45.0
16th										
Ta	25.0	27.0	29.5	31.0	31.5	32.0	29.5	27.0	33.0	26.0
Tn	29.5	29.0	29.0	28.0	27.0	26.0	29.	29.5	30.	28.5
Tc	27.5	35.5	57.5	68.5	70.0	75.0	50.0	46.5	65.0	32.0
17th										
Ta	25.5	26.0	28.0	32.0	30.0	31.0	32.0	31.5	31.0	30.0
Tn	27.5	27.0	27.0	27.0	28.0	27.5	27.0	27.5	28.0	28.0
Tc	26.5	30.5	45.0	54.0	59.5	63.0	67.0	64.0	58.0	52.0

Table 1: contd.

H	7	8	9	10	11	12	13	14	15	16
19th										
Ta	25.5	26.5	31.0	31.5	32.0	32.5	33.0	32.5	31.0	30.0
Tn	27.5	27.0	27.0	26.0	26.0	25.5	26.0	27.0	28.0	29.0
Tc	30.0	33.5	53.0	60.0	62.0	66.0	72.0	71.0	70.0	64.0
20th										
Ta	23.0	25.5	27.0	29.0	30.0	31.0	28	30.0	32.0	33.5
Tn	30.0	29.5	29.0	28.5	28.0	27.0	28.5	29.0	28.0	26.5
Tc	27.0	38.0	48.0	60.0	73.5	75.0	67.0	57.0	71.0	80.0
25th										
Ta	20.0	23.5	26.0	26.5	28.0	29.0	27.0	29.0	25.0	24.5
Tan	29.0	27.0	25.0	31.5	25.0	26.0	25.0	26.0	26.0	26.0
Tc	25	27.0	28.0	25.5	49.5	51.5	43.0	48.0	46.0	48.0
26th										
Ta	25.5	28.0	28.5	29.0	30.0	32.0	31.0	28.0	28.5	
Tn	29.5	29.0	28.0	27.0	27.0	26.0	27.0	29.0	29.0	
Tc	35.0	49.0	54.0	56.0	61.0	69.0	52.0	62.0	59.0	
Mean	24.75	26.50	28.14	29.18	30.30	31.23	30.79	30.00	30.10	24.9
Temp	29.00	28.50	28.14	27.10	27.00	26.50	27.10	27.70	27.90	27.80
(°C)	28.83	37.75	46.50	55.14	63.90	67.64	61.73	60.62	60.71	54.17

Temperature collector for the month of July

Table 2: Iridance as measure in month of July

H	8	9	10	11	12	13	14	15	16	Remark
15th										
Ib	180.0	223.3	342.5	403.6	429.0	415.8	405.6	323.0	256.2	clear
S	87.5	101.5	151.3	176.6	185.9	181.9	179.2	146.9	118.0	
	-	94.7	126.4	164.0	181.3	184.0	180.6	163.1	132.5	
16th										
Im	185.1	235.1	352.8	402.5	504.4	450.1	435.2	323.6	200.0	Clear
S	89.7	106.4	156.1	176.1	218.6	197.2	192.3	147.1	96.9	
	-	98.1	131.3	166.1	197.4	207.9	194.8	169.7	122.0	

H-----	8	9	10	11	12	13	14	15	16	Remark
17th										
Ib	174.9	224.8	278.0	349.9	456.7	431.6	388.3	257.8	201.0	Shalowy
S	84.5	101.6	122.7	153.2	199.2	189.1	171.4	116.6	97.2	
	-	93.1	112.2	138.0	176.2	194.2	180.3	144.0	106.9	
19th										
Ib	205.0	250.1	300.0	345.1	480.1	490.2	450.0	400.0	346.8	Clear
S	99.1	112.7	132.5	150.9	209.5	214.3	198.5	180.4	181.9	
	-	105.9	122.5	141.6	180.2	211.9	206.4	189.4	181.2	
20th										
Ib	203.0	245.1	315.1	360.0	400.0	385.0	271.1	365.1	390.1	Clear
S	97.5	110.0	139.0	157.4	172.0	168.3	119.0	164.4	187.5	
	-	103.8	124.5	148.2	164.7	170.2	143.7	141.7	176.0	
25th										
Ib	174.	258.0	290.0	315.0	350.0	410.0	278.0	200.0	180.0	dull
S	82.5	115.3	127.4	137.2	156.5	150.2	122.0	89.4	84.9	
	-	98.9	121.4	132.3	145.9	153.4	136.1	105.7	87.2	
26th										
Ib	150.0	200.1	317.8	370.0	425.0	402.1	414.8	389.3	305.0	Shalowy
S	70.9	89.3	139.4	161.0	184.6	176.3	181.9	173.7	144.8	
	-	80.1	114.4	150.2	172.8	180.5	179.1	177.8	159.3	

COLLECTOR TILT 24.75, CONCENTRATION RATIO 16.23

H	T_a	T_c	S Wm^{-2}	η (%)	$T-T_a/I$
8	299.5	451.7	87.8		33.7
9	301.1	468.9	101.5		35.8
10	302.3	518.1	151.3		41.7
11	303.3	538.5	176.6		43.7
12	304.3	545.5	185.9		44.2
13	303.8	542.5	181.9		44.9
14	303	540.5	179.2		44.9
15	303.1	514.3	146.9		41.1
16	298.0	486.9	118.0		38.8

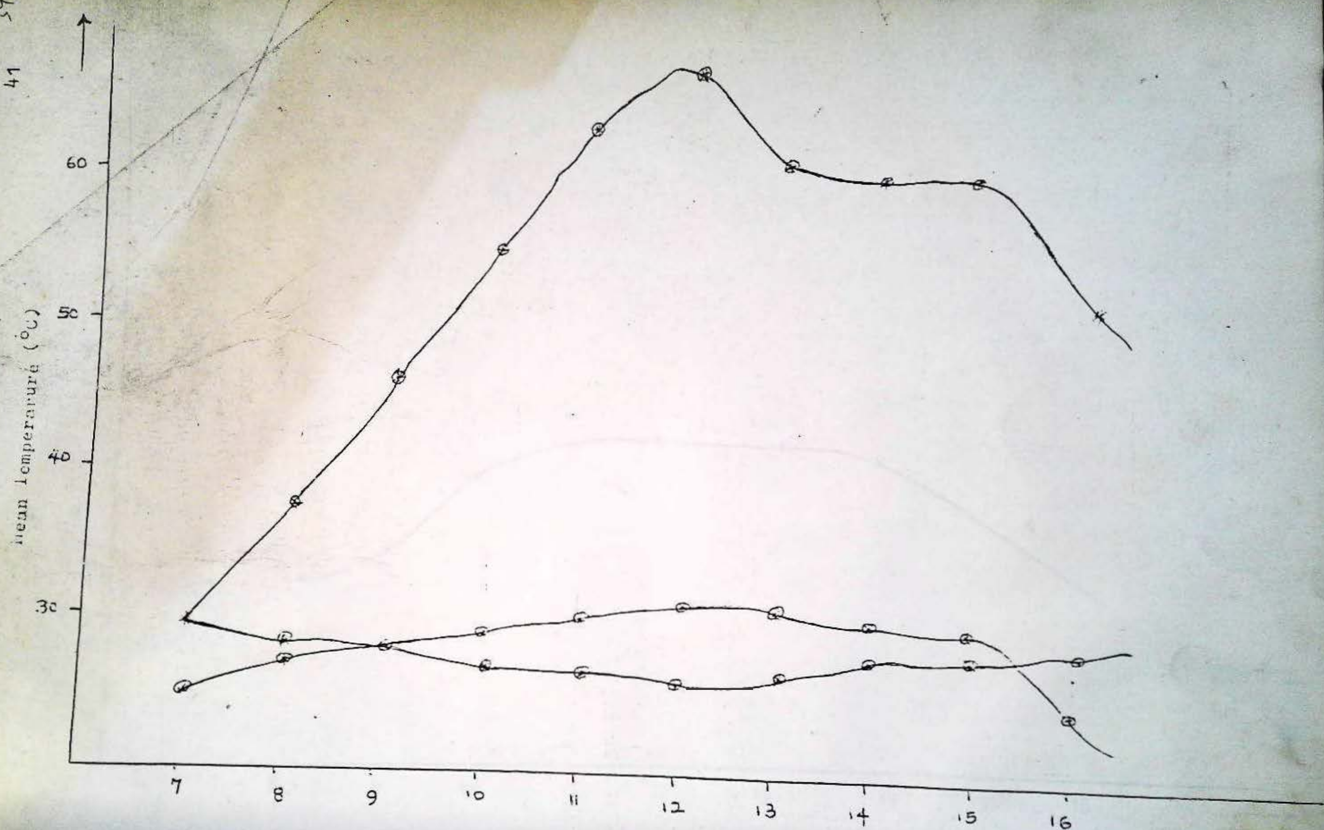

Fig. 5.1 Plots of Average Temp Against Local time

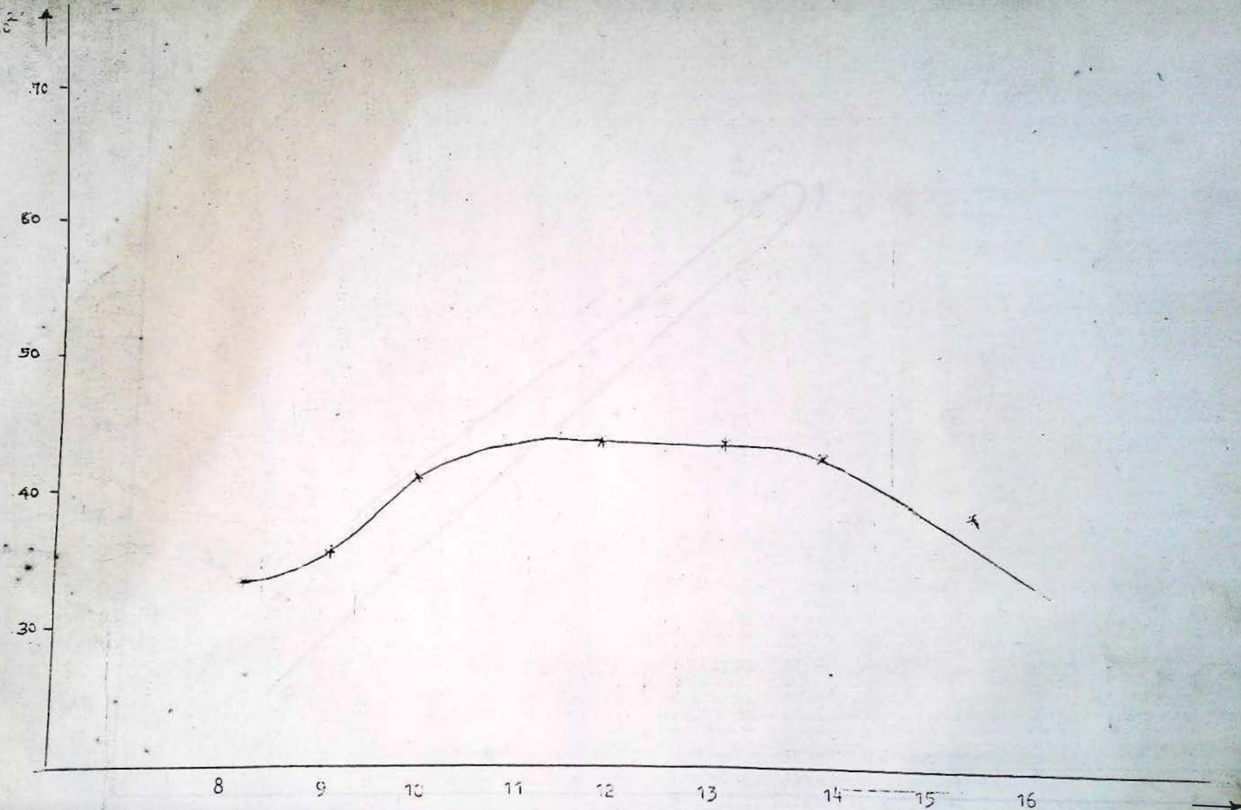

Fig. 5.2 A plot of collector efficiency against local time

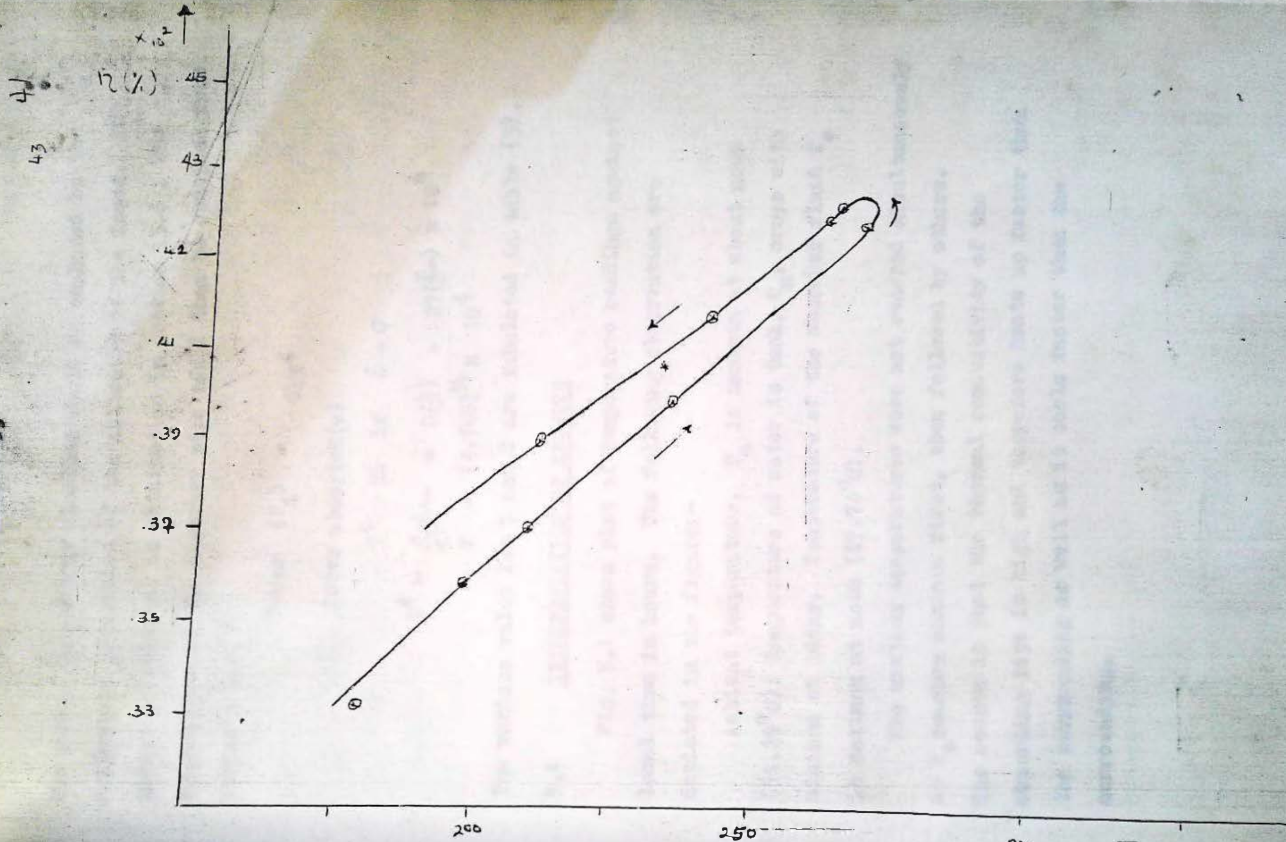

Fig. 5·3. Plot of Efficiency Against Temperature the year. The energy absorbed would be enhanced by the reflecting properties of the collector to the focus. The energy absorbed(s) is obtained as in section (3.6). The temperature of the absorber pipe could then be obtained from Stefan's law.

$$\text{Power } (P_1) = \sigma \varepsilon T^4$$

Power absorbed(s)

$$T^4 \quad SA \quad \text{if} \quad \varepsilon = \sigma$$

$$T^4 = \frac{S.A.}{\sigma} = S(\frac{A}{\sigma}) = 27(\frac{S}{\sigma}) \times 10^8$$

$$T = (4.76S)^{1/4} \times 10^4$$

The various value for T and S are tabulated in table (3).

5.4 INTERPRETATION OF RESULTS

Fig, 5.1 shows plot of temperature readings against local time in hours. The following observation are depicted in the figure:-

Ambient temperature, T_a is maximum at about noon (31.29°C); Temperature of water is tank, T_n, crops with minimum at idday. Temperature of the absorbed fluid T_o is maximum at noon (67.74°C).

The maximum temperatures were not reached simultaneously as T_o reaches maximum first, then followed by others. The reason is that the thermal conductivity of the absorbing pipe is high and therefore heats up faster than the surrounding as well as it cools faster than the surrounding.

T_m is almost constant without much appreciable rise in temperature, which is due to the small amount of heated water returning back to the task. The temperature drops during the day and reaching its minimum at about noon and gradually risen. This small amount of heat added to the water is absorbed readily when the water is being stirred when reading were observed. Water has high specific heat capacity and therefore takes a long time to heat up, the small heat added take a long time to heat up the water and when the water is heating, the sun is no longer overheat intensity of solar real is dropping. The efficiency of storage depends on insulation of the tank.

The curve of fig. 5.3 shows that efficiency increases linearly from 33% at 8 a.m. to about 44.29% at about 12.30p.m. with collector temperature. There is a turning point at about 44.25 percentage efficiency. This occurs at about 12.30p.m. after which efficiency decreases linearly with time.

This decrease was obtained from 44.25% to 38% between 12,30pm and 4.00p.m. Maximum efficiency of 44,25% was obtained when the collector temperature reached 273.3°C as seen from the carve of 5.3.

The sharp negative change of the collector efficiency is due to the fact, that as from 12.30p.m. when the collector has passed through a maximum the solar intensity decreases linearly with time. Fig. 5.2 shows the curve of efficiency against time.

CHAPTER SIX

DISCUSSION AND CONCLUSIONS

6.1 SUMMARY

Solar energy, its availability, application and limitation were reviewed in chapter one. Solar collectors were also reviewed in chapter two, and the theory of the cylindrical solar energy collector was discussed in chapter 3. The design and construction of the cylindrical collector was treated in chapter four. Measurements, results and their interpretations were presented in chapter five.

Results obtained showed a storage tank efficiency of 41% and a collector efficiency of 44.25%. The difficulties encountered, suggestions and conclusions, were discussed in chapter six.

6.2. DIFFICULTIES

The difficulties encountered in this project work include: 1. Getting a material with near 100% reflecting surface (high reflectance) which would reflect, most or all the incident flux and absorbs none or small. It should not also lose its reflecting properties fast. All metal polished surface energy. Silver was more promising but could not be afforded due to cost and also aluminuin which was not even available in the market at the time in question.

T_{in} was the only option left but its effective performance was hindered seriously by rust, also its inability to withstand stress and strain.

ii. Surface irregularities and non-exact parabolic trough could not be avoided in the course of construction.

iii. Lack of measuring solar radiation instrument was another drawback. The use of a radiation measuring apparatus like the solarimeter would have enhanced the precise measurement of the intensity of radiation onto the absorber and improved the efficiency of the collector.

In taking the temperature of water from the absorber, which was made possible with the use of an ordinary thermometer through disconnection at the outlet. is not a very good method, because water loses heat at the time of spurting and the temperature is therefore lowered before measurement is taken. This water temperature was assumed to be the absorber temperature thus then absorber temperature has been grossly underestimated.

iv. The material used for the tank rusted after some time. This form an oxide sludge at the bottom of the tank. As the water is stirred or refilled the sludge gets into circulation and the fine deposite clogged to the absorber pipe presenting a resistance to heat transfer.

v. Seasonal variation in weather was another set-back! in the course of the work. Cylinderical collector like other collectors uses only the beam component of solar radiation. During this period the amount of water content in the atmosphere is high. water vapour strongly affect the infra-red region of the solar spectrum, causing scattering of solar radiation. The result is that the solar radiation received is mainly diffuse. This diffused

This diffused radiation causes water to evaporate hence increasing humidity.

6.3 COST OF CONSTRUCTION

The cost of the solar water heater consists of the following:-

ITEMS	₦ k
Tin sheets (₦150 x 10)	1,500.00
2.3 x 2.3cm square used for base construction	350.00
Brazing rod (₦50 x 8)	400.00
Aluminium pipe (absorber) 1.27m	150.00
Rubber tube 4 yards	150.00
Aluminium foil	100.00
Screws, clips, and gum	120.00
Glass tube 1.2m	400.00
Packing foam	80.00
Workmanship	250.00
Total	3,500.00

From the list, a total of ₦3,500.00 spent on such heater is not too expensive compared to its duration. Such solar heater can function for years after installation without the need for repair or spare parts.

6.4 SUGGESTION FOR FURTHER WORK

Suggestion for continuation of research work in this direction should look into areas such as:-

Increasing reflecting properties of non-metals, by electroplating or depositing selective materials with good reflecting properties on the surface. These non-metal should be durable and can withstand strain and stress during fabrication.

If it could be done on plystere it would help solve one great problem with focusing collectors. Mirrors are good reflectors but there is the question of durability.

A dc amplifier with amplification factor of about 200 will be required to the use of a thermo-couple.

Storage tank should be painted so that it would not rust quickly or a material like aluminuim should be used. Inside should be lined to father reduce the heat loss. Though insulation is provided for single tank. Double tank system should be encouraged, as the tank holding the thermic fluid is insulated from environmental interraction, unlike the single tank system.

Edge loss should be minimised. Proper insulation for the edge tube-glass system should be provided. The effect of altitude on collector performance should be looked at.

655 CONCLUSION

For continuity and difinite results, a research unit well funded need to be established. A commercial sector in operation for the production of solar equipment would be desirable.

Nigeria having been blessed with abundant sunshine, should view research into solar energy seriously. It would produce a cheap alternative source of power. More especially in the rural areas where electricity is not available and help conserve our natural resource.

Even countries in temperate climates of the world are engaged in solar energy research. Nigeria should not be left out.

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