DESIGN, CONSTRUCTION AND TEST OF A PASSIVE SOLAR TRACKING DEVICE

BY

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DECLARATION

I declare that the work in the project titled the Design, Construction and Test of a Passive Solar Tracking Device has been performed by me in the department of Mechanical Engineering Under the supervision of Dr. E.J Bala. The information derived have been duly acknowledged in the text and a list of references provided. No part of this project was previously presented for another degree or diploma at any university.

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CERTIFICATION

This thesis entitled 'DESIGN, CONSTRUCTION AND TEST OF A PASSIVE SOLAR TRACKING DEVICE' by EDEBI, Odafe Umenu meets the regulations governing the award of Masters of Science – Mechanical Engineering (Energy studies) of the Ahmadu Bello University, Zaria – Nigeria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This project is dedicated to Jesus Christ my Advocate with God Almighty.

ACKNOWLEDGEMENT

I wish to express my appreciation to Dr. EJ Bala, my supervisor for his advise. I also wish to sincerely appreciate Prof CO Folayan for his constructive criticism, useful advise, and continous encouragement throughout the period of this study.

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At this point I want to say to my wife, Mrs Binta Odafe Edebi, I love you for all your love and care you showered me with thus far and to tell you that without you all this would not have been possible.

Finally, I give thanks to God Almighty for his grace that has seen me through.

Odafe W. U. Edebi

ABSTRACT

This project is aimed at designing, constructing and testing of a single axis, variable speed passive solar tracking device. This is because all the solar trackers in use in the country are mainly imported.

The design works on the principle that Freon – 12 (Dichloroflouromethane) boils at very low temperatures i.e. somewhat lower than – 30^0 F (-34.44^{o}C) thus generating great pressures even with just a small quantity of it evaporating. This pressure generated from the evaporation of some of the Freon – 12 tilts the collector in the direction of the sun through a hydraulic cylinder pivoted to the collector base.

The solar tracker was designed, constructed, and tested by mounting a solar Photovoltaic (PV) module on the tracker and comparison of the power output of the PV module on the tracker against that of a stationary PV module was made. Results showed that the tracking panel had an average relative performance of about 30% over the stationary module and a cost of over N40, 000.00 cheaper than that of the imported one.

It was thus concluded that the project was a success because the relative performance obtained is in agreement with reported performances of similar tracking devices.

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SYMBOLS

A	-	Altitude Angle (degrees); Area (m^2)
D	-	Declination (Degrees)
D_o	-	Outer Diameter (m^2)
D_i	-	Internal Diameter (m^2)
L	-	Latitude Angle (Degrees); Length (m)
H	-	Hour Angle (Degrees)
Y	-	Angle of incidence (Degrees)
S_T	-	Angle of slope (Degrees)
Z	-	Surface azimuth Angle (Degrees)
V	-	Volume (m^3)
F	-	Force (Thrust) (N)
d	-	Diameter (m)
R	-	Specific gas constant (KJ/kgK)
R	-	Universal gas constant
m	-	Molar mass of the gas; mass (Kg)
T	-	Temperature (K)
P	-	Pressure (N/m^2)
ρ	-	Density (kg/m^3)
Y_T	-	Angle of incidence on tilted surface (Degrees)

Y_O - Angle of incidence on horizontal surface (Degrees)

1_b - Beam radiation

1_d - Diffuse radiation

V_{RC} - Volume of Refrigerant cylinder (m^3)

V_{RR} - Volume of Refrigerant Reservoir (m^3)

T_{SC} - Tensile strength of copper (N/m^2)

CHAPTER ONE
INTRODUCTION

1.1 SOLAR ENERGY

Solar energy is an important clean, cheap and abundantly available renewable energy. The sun radiates heat and light. The heat and light received from the sun support the environment on the earth through the following well-known natural effects.

- Temperature balance on the earth
- Photosynthesis by biological plants, production of oxygen and organic materials. Production of organic chemicals and biomass
- Wind due to unequal heating of water, land surfaces.
- Water cycle: Evaporation – Clouds – Rain – water – evaporation - clouds - …
- Heating of ocean water: Ocean thermal energy (OTEC)
- Waves in Ocean: Ocean wave energy
- Tides in Ocean: Ocean tidal energy (due to gravitational forces._

The sun produces enormous amount of heat and light through sustained nuclear fusion reactions. The solar energy received on earth and can be used for heating and producing electrical energy.

The first person to use the sun's energy on a large scale was Archimedes who reportedly set fire to an attacking Roman fleet at Syracuse in 212BC. He accomplished this by means of a burning glass composed of small square mirrors moving everywhere upon hinges so as to reduce the Roman fleet to ashes at a distance of a bowshot. Serious studies of the sun and its potentials began in the 17th century when Galileo and Lavoiser utilized the sun in their researches. By 1700 diamonds had been melted and by the early 1800s heat engines were operating with energy supplied by the sun. In the early twentieth century, solar energy was used to power water distillation plants in Chile and irrigation pumps in Egypt. (Kreider and Kreith, 1981).

About 170 trillion KW of solar energy are intercepted by the earth, an amount which is 5000 times greater than the sum of all other energy inputs, {Dickinson and Cheremisinoff, 1980). 30% of this amount is reflected back into space as short wave radiation, 45% is absorbed by the atmosphere, the land surface and oceans and it is converted to heat as the ambient surface temperature of the planet. The remaining 25% powers the evaporation, convection and precipitation cycles of the biosphere.

1.2 SOLAR TRACKING

Although it is abundant, solar energy impinging on the earth's atmosphere is relatively small due to attenuation, local weather phenomena and air pollution. Also solar energy is received in cyclic, intermittent form with very low power density from 0 to $1kW/m^2$. The direction of solar rays changes during the day and with season. Solar energy received on ground level is affected by atmospheric clarity, degree of latitude etc.

There is therefore a need to harness the cyclic and intermittent though abundant solar energy. One way of doing this is using solar collectors. Collectors are devices which absorbs and transfers the solar energy to heat transport fluids. Solar Collectors could be flat plate, paraboloic trough, Heliostat – reflector or Fresnel.

These collectors are usually operated in a fixed position oriented in a north-south direction in the northern hemisphere titled at an angle approximately equal to the latitude angle of that location. The collector performance and efficiency are usually expressed in terms of solar energy incident on the collector. A method that has been receiving attention in recent times for increasing the output of the collectors is that of making the collector track the sun.

For the rays to be normal to the collector surface requires that the collector follows the sun both in the east- west and in the north- south directions continuously. This type of collector is known as the fully tracking collector. A restricted form of tracking, called semi-tracking may however be obtained by restricting the collector to rotate about a north – south axis, with the collector inclined to the horizontal at an appropriate slope. Two cases may be distinguished: one when the normal to the collector rotates at a uniform speed of 15^0 per hour and the other when the normal to the collector is always in the azimuthal plane. The later case, though better, requires that the collector be rotated at rotational speeds which vary over the day. The last type of semi tracking is by constraining the collector to rotate about a east – west axis, which itself is inclined to the horizontal at an appropriate slope usually the latitude angle of the location. This is usually done on a monthly basis.

1.3 SOLAR COLLECTORS

When sunlight strikes an object, a portion of the energy bounces off (reflection). The remainder serves to increase its molecule activity causing a corresponding rise in temperature.

The above discussion shows the relationship of sunlight to thermal energy conversion process. The conversion takes place automatically on contact between sunlight and a material. To be able to utilize the sunlight – to – thermal phenomenon effectively requires a device capable of heating up efficiently, able to transfer the collected heat to some kind of heat transfer fluid (either air or a liquid) and be able to do this while exposed to outdoor weather conditions. The most popular device at present capable of fulfilling this is called a “flat – plate collector”. All flat plate collectors have five basic components in common namely:

a. The absorber surface

b. The heat transfer interface/fluid passage

c. The Glazing

d. The insulation and

e. The protective casing

Flat plate collectors could either be Liquid cooled or air cooled Flat plate collectors. Water or a water/antifreeze solution is used predominantly as the heat transfer (heat removing) Fluid in liquid cooled flat plate collectors. Non toxic anti freezes and silicon based heat transfer fluids are also being developed specifically for use in solar energy collection systems. Air cooled Flat plate collectors use air as the heat transfer medium.

1.4 SOLAR PHOTOVOLTAIC CELLS

Photovoltaic (PV) is the direct conversion of sunlight to electricity through photoelectric effect. The smallest unit of a solar electric device is the solar cell. Solar cells are made of semi conductor material of which the commonest is silicon. The silicon cell may be from monocrystaline, polycrystalline or amorphous silicon. Monocrystaline refer to cells cut from single crystal of Silicon while polycrystalline refers to cells made from many crystals. Amorphous type cells are made from silicon that is not in crystalline form. Instead silicon is deposited on the back of a glass or surface in very thin layers. The surface is then scored to divide it into a number of cells and electrical connections are added.

Mono and poly crystalline silicon cells are silicon wafers sliced from cylindrical silicon crystals using very precise saws. These wafers are then chemically treated in furnaces to enhance their electrical properties, after which an anti reflective coating is applied to the cell surface to help it absorb radiation more effectively. Thin metal wires are soldered to the front of the cell. These ribbons of metal on the cell act as the contact, whereas a solid layer of metal on the back side of the cell acts as a negative contact.

1.5 SOLAR MODULE

Arrangement of solar cells wired in series sealed between glass and plastic and supported inside a metal frame is called a solar cell module. A standard module will produce 12 volt, 3.5 Amp at maximum power point. While a solar array is a group of modules mounted together.

1.6 NEED FOR TRACKING

Tracking requires that the collectors receive sunshine early and late in the day to be effective. At mid and high latitudes the summer gain is significantly greater than the winter gain which typically is not more than 20%.(Paruleka and Rao, 1999).

Solar tracking increases the amount of time solar collectors are oriented towards the sun and therefore increase the solar collector output. Solar tracking could to a lesser degree be used for control functions. In a situation where an optical lens is to be used to track the sun's movement, there would be a reduction in the cost of the lens since the tracker allows the incident rays to strike normal to the lens and therefore smaller lenses are required.

1.7 THE AIM OF THE PROJECT

The aim of this research work is to design, construct and test a solar energy tracking device to which a solar module can be incorporated.

The aim is to be achieved by the design of a single axis variable speed passive solar tracking device after which construction of the tracker using the design criteria would be undertaken.

A solar tracking device will maximize the amount of time the solar module is oriented towards the sun thereby maximizing the energy output from the solar module. It is also hoped that after the construction and experimentation on the performance of the device, some useful information would be gained which could lead to improvement on the design.

CHAPTER TWO
LITERATURE REVIEW

2.0 SOLAR TRACKERS

Solar trackers are machines for orienting solar systems towards the sun. They are used to maximize the amount of time solar devices are oriented towards the sun to keep optical elements properly focused and for control purposes. The purpose of solar trackers is to get the highest possible output from costly photovoltaic panels.

Solar trackers may be “active” or passive. Active trackers use motors and gear trains that direct the tracker as commanded by a controller responding to the solar direction. Passive trackers use a temperature sensitive fluid that is driven to one side or the other to cause the tracker to move in response to an imbalance.

2.1 TRACKING MODES /GEOMETRIES

There is the single axis and dual axis trackers, but only the dual axis trackers are fully tracking.

Dual Axis Trackers: There are two main types of dual axis trackers, equatorial and alt-azimuth (azimuth angle refers to the direction of the tracker that corresponds to the compass directions, north, south, east, west).

Equatorial tracking is rotation around an axis parallel with the earth’s axis at about clock speed. The second axis compensates for the change of declination, the earth’s tilt relative to the direction of the sun as the earth circles the sun. Since the earth’s tilt is currently 23.5 degrees, the total change is 47 degrees during summer (rainy season) and winter (Dry Season). Alt-azimuth tracking is rotation about a vertical axis with the altitude of the sun compensated for by rotation around a horizontal axis.

Single Axis trackers are simpler than dual axis trackers. Basically these are trackers where the axis runs north-south and those where the axis runs east-west. On east-west trackers the axis is almost always horizontal whereas on north-south trackers the axis can be tilted any amount with the three special cases: horizontal (sometimes called SMUD) vertical (azimuth) and parallel with the earth's axis (polar) as with equatorial tracking. Single axis tracking can be very effective. Polar and azimuth tracking capture more than 95% of full tracking on a yearly basis. Azimuth trackers rotate around a vertical axis so that the tracker and the collectors are at the same azimuth angle of the sun. (Azimuth angle refers to the direction of the tracker that corresponds to the compass direction north, south, east, west). An azimuth tracker with its collectors properly tilted captures over 96% of all sunshine per year with no adjustments. This percentage is about the same as an unadjusted equatorial tracker but the character of the output of the two geometries (azimuth and equatorial) is different. In the temperate region, the azimuth tracker is at its best in spring, fall (autumn) and winter and at high latitudes. In summer when there is the greatest amount of sunshine, output is shaved from the mid day peak so the output stays very constant throughout the day. If adjusted twice a year, a slight increase in effectiveness can be achieved in the summer and the winter output is helped even more, capturing almost 100% of full tracking at the winter solitice (Dec 21)

Put more concisely single axis trackers move throughout the day following the path of the sun across the horizon while two (Dual) axis tracking system not only follow the path of the sun throughout the day, but they also adjust their horizontal angle throughout the year in response to the position of the sun in the sky as it changes from season to season.

2.3 PREVIOUS WORK ON SOLAR TRACKING SYSTEM

Quite a number of works have been done in the design and construction of solar tracking devices. A few of the works reviewed in the course of this research are as follows:

Atiku, Suleiman and Aliyu (1989) designed, developed and evaluated the operational performance of a single axis microprocessor controlled solar tracker for photovoltaic systems. The researchers came to the conclusion that:

i. The developed solar tracker is capable of tracking the sun's motion using sun finding sensors alone, provided the sun's array line is within the angular field of view of the sensing mechanism

ii. The combined operation of the power point tracking yields an optimally aligned photovoltaic module when maximum power delivery is desired at any insolation level.

iii. The time base sun motion tracking ensures discrete motion of the module with the same speed as the sun. This is achieved independent of sun sensors, thereby eliminating their associated problems.

Atiku (1987) designed and developed a microprocessor controlled solar tracker for photovoltaic module as his M.Sc thesis at the Ahmadu Bello University Zaria.

Salawu and Oduyemi (1983) designed and constructed an electronic sun finder and solar tracker which consisted of two photodiodes separated from each other by an opaque body in an enclosed rectangular structure. Two pairs of solar cell were mounted in quadrature externally on opposite sides of the structure. The cells were connected to a different amplifier whose output is used to drive a direct current motor through a relay. The solar cells activated the relay whenever light of unequal intensity falls on them and the output of differential amplifier then drives the motor to align with the sun.

The researcher came to the conclusion that the tracker, tracked reasonably well and that there was no lag time between the shift of the sun and the movement of the tracker.

Salawu and Aina (1983) designed and tested an electronic solar tracker.

This work intends to design construct and test a purely mechanical tracker as all the trackers reviewed had some form of electronics/electrics incorporated into their working.

2.3 JUSTIFICATION

Solar tracking has been shown to improve the efficiency of solar panel collectors by increasing their output by as much as 35% for dual axis tracking and 25 – 30% for constant speed and variable speed single axis tracking.(Arinze et al.,1988).

In Nigeria very little has been done on tracking for a country with abundant solar energy. This work intends to design a purely mechanical tracker, requiring no external source to power it. This tracker is intended to give maximum net output from a PV module.

A locally fabricated tracker is also intended to avoid the importation of these trackers which cost a fortune to bring into the nation.

CHAPTER THREE
THEORY OF DESIGN AND DESIGN CALCULATIONS

3.1 ANALYSIS OF TRACKING

The key component in solar heating, cooling and electric power generation systems is the solar collector, and of this, the most widely used is the flat plate solar collectors and more recently photovoltaic modules. The collector performance and efficiency are usually expressed in terms of the collector useful energy gain and total solar energy incident on the collector. Effective design and utilization of solar collector depend to a large extent on the knowledge of insolation characteristics of the region in which the collector are to be located. In this case, the tropics.

Flat plate collectors absorb beam radiation diffuse radiation and solar radiation reflected from the ground. In order to calculate the maximum absorbed radiation for tracking flat plate collectors, we need to relate the radiation incident on the collector to the total radiation on the horizontal surface. This is usually represented by the angular correction factor F. For a fully tracking flat plate collector, the slope of the collector must be equal to the complement of the sun's Altitude angle A.

3.1.1 ANGLE OF ALTITUDE (A)

This is the sun's apparent position from any point on the earth relative to the horizontal, (Rapp 1981).

$A = \sin^{-1} \{ \cos D \cos H \cos L + \sin D \sin L \}$-----3.1

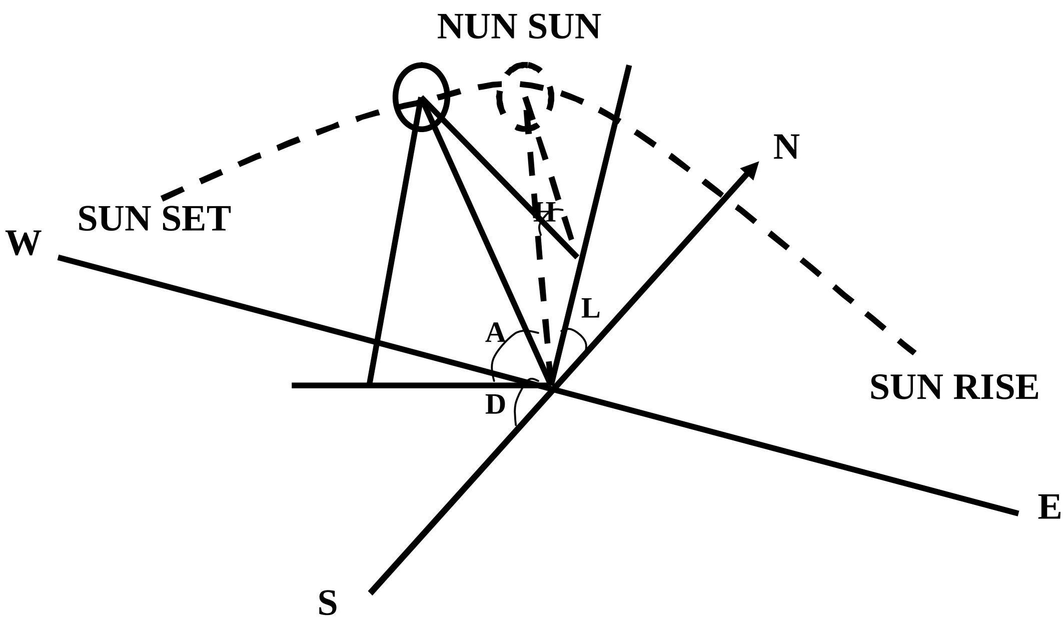


Fig 3.1 Apparent motion of the sun at latitude L

D = Solar Declination

L = Latitude Angle of location

H = Hour Angle

3.1.2 ANGLE OF SLOPE (ST)

This is equal to the complement of the altitude angle for a fully tracking flat plate collector, (Rapp 1981).

$$S_T = \text{Cos}^{-1}\{\text{Sin D Sin L} + \text{Cos D Cos L Cos H}\} \text{ ------3.2}$$

3.1.3 ANGLE OF INCIDENCE

The angle of incidence for a tilted fully tracking collector is given by Duffie and Beckman (1974).

Cos Y = Sin D Sin L Cos S_T - Sin DCos L SinT Cos Z + CosDCosL Cos S_T CosH + CosDSinLSinTCosZ+CosH + CosDSinTSinZ+SinH --------3.3

Where Z = Surface azimuth angle.

3.1.4 SURFACE AZIMUTH ANGLE (Z)

This is the angle made in the horizontal plane between the projection of the normal to the plane on the horizontal plane and the line due north to south. For a fully tracking collector, the collector azimuth angle must be equal to the sun's azimuth angle. For a surface facing south Z = 0. (Donald Rapp 1981).

3.1.5 ANGLE OF DECLINATION OF THE SUN

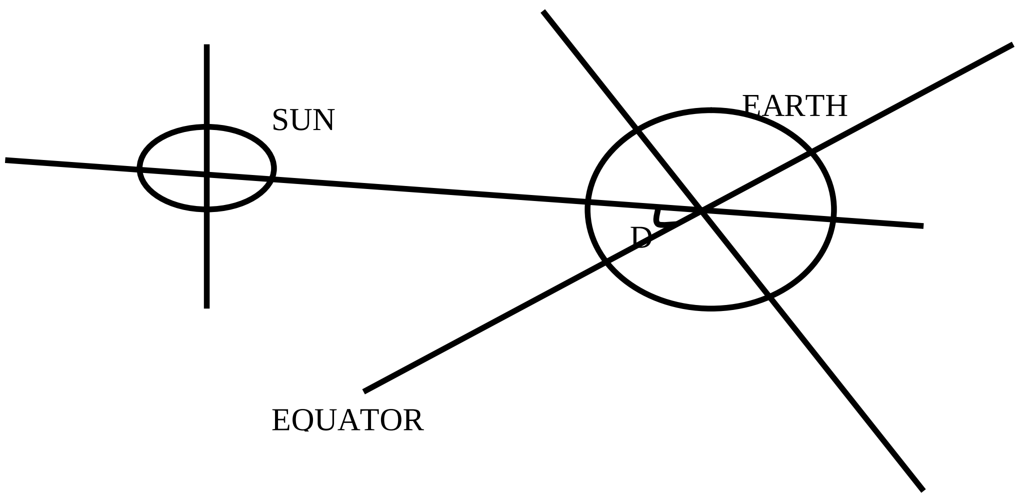


Fig 3.2 Angle of declination

The angle of declination is the angle between the line joining the centre of the sun and earth and the equatorial plane. The angle of declination. (D) varies with season from maximum value of $+23.45^o$ on June 21 to minimum value of -23.45^o on December 21. The angle of declination is zero at two equinoxes ie March 21 and September 21. (Paruleka and Rao, 1999).

$$D = 23.45 \text{sun} \frac{360}{365} (284 + n) \quad \text{--------3.5}$$

Where n = the day of year counted from first January i.e. 21 June =172 Paruleka and Rao, (1999).

3.1.6 HOUR ANGLE (H)

This is the angle tracked by the sun in 1hour with reference to 12 noon and is equivalent to 15^0 per hour.

$$H = \frac{t}{24} .360^0 \quad \text{------------3.6A}$$

H = 15t Degrees Brinkworth (1972) where t =12 –LAT --------3.6B

LAT =Local apparent time

LAT =Standard Clock + 4 (Standard Longitude – Longitude of for clock time time the location)

+ Time correction Paruleka and Rao, (1999) ---------- 3.6 C

H is positive in Afternoon and Negative in forenoon.

3.1.7 TOTAL SOLAR RADIATION ON A TILTED SURFACE (I_T)

The ratio of direct radiation on a tilted surface to the direct radiation on a horizontal surface is

$$R = \frac{\text{Cos } \theta_T}{\text{Cos } \theta o}$$

θ_T = angle of incidence on tilted surface

θ_o= angle of incidence on horizontal surface

The procedure outlined by Lui and Jordan (1963) is used to evaluate the conversion factor for diffuse radiation and the reflected radiation from the surrounding.

A surface titled at slope B from the horizontal has a view factor to the sky given by (1 + Cos B)/2. The surface has a view factor to the ground of (1 – Cos B)/2 and if the surrounding has a reflectance of P, the reflected radiation from the surrounding surface from the solar radiation is $(1_d + 1_b)$ P (1 _ CosB)/2. Combining the three components, the total solar radiation on a titled surface is given by

$1_T + 1_b$ R + 1_d (1 + CosB)/2 + $(1_b + 1_d)$ P (1 – Cos B)/2 --------- 3.7B

where

1_b = Beam radiation

1_d = Diffuse radiation

For now snow cover Lui and Jordan suggested a ground reflection P of 0.2.

3.2 VOLUME OF A CYLINDER (V)

This relates to the volumes of the Freon reservoirs and the hydraulic cylinders.

Volume of a cylinder = Cross Sectional Area x Length

Area (A) = $\frac{\prod d^2}{4}$

3.3 PRESSURE IN A CYLINDER (P)

This also relates to the volumes of the Freon reservoirs and the hydraulic cylinders.

$$\text{Pressure in Cylinder (P)} = \frac{\text{Force}}{\text{Cross Sectional Area}} = \frac{F}{A}$$

$$= \frac{4 \times \text{Force}}{\prod^2 d} = \frac{4F}{\prod d^2} \quad \text{--- 3.9}$$

3.4 SPECIFIC GAS CONSTANT (R)

This equation helps to treat Freon in its gaseous state. On heating the Freon, some quantity will boil off and will be treated as a gas. Then its gaseous pressure can then be calculated.

For any gas

$$R = \frac{R}{m} \quad \text{-----} \quad 3.10$$

where

R = universal gas constant

m = molar mass of the gas

3.5 IDEAL GAS EQUATION

For an ideal gas, the temperature volume, pressure, mass and the specific gas constant are related by

$$PV = mRT \quad \text{---------} \ 3.11$$

Where P = Pressure of the gas at a specific temp

V = Volume of the gas

T = Temperature of the gas

m = Mass of the gas

R = Specific gas constant

3.6 LENTH OF THROW – ARM

The length of the throw arm is of great importance. If placed too far from the pivot point, the tracker will not track because this pivot length must be designed to work with the piston length of the hydraulic cylinder.

$$\text{Throw Arm length (Radius)} = \frac{\text{Arc Length (in mm)}}{\text{Angle Subtended (in Radians)}} \quad \text{---------------(3.12)}$$

$$= \frac{\text{Piston Stroke}}{2 \times \text{Altitude Angle in Radians}}$$

3.7 MAXIMUM PERMISIBLE PRSSURE IN REFRIGERANT RESERVOIR

This estimates the maximum safe pressure that could be withstood by the material chosen to act as the reservoir thus eliminating the chances of using excessive pressures.

$$\text{Maximum Pressure N/m}^2 = \frac{\text{max wall thickness x 2 x tensile strength}}{\text{Outside Diameter of conductor}} \quad ..(3.13)$$

$$\text{Working Pressure N/m}^2 = \frac{\text{max Pressure N/m}}{\text{Factor of safety}}$$

3.8 FORCE ON HYDRAULIC CYLINDER

The thrust force that may be obtained is dependent on the area of the piston and the pressure.

$$F = \frac{\Pi D^2 P_1}{4} - \frac{\Pi (D^2 - d^2) P^2}{4} \text{ -------- } (3.15)$$

Where D = Outside Diameter of hydraulic cylinder
d = internal diameter of hydraulic cylinder
P_1 = inlet pressure
P_2 = Outside Pressure

3.9 MASS OF A FLUID

This estimates the volume of fluid required to fill the Freon-12 reservoir

$$\text{Density} = \frac{\text{mass}}{\text{Volume}} \text{------------} (3.16)$$

$$\rho = \frac{M}{V}$$

ρ = Density kg/m^3

M = mass = kg

V = Volume = m^3

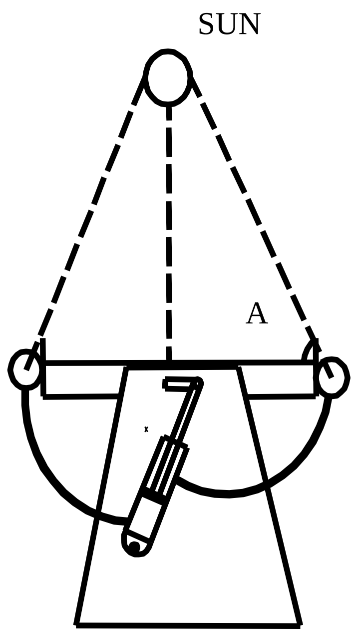
3.10 DESIGN OF SEMI – TRACKING VARIABLE SPEED SOLAR TRACKING DEVICE

This design of the semi tracking variable speed solar tracking device is based on the fact that gas when subjected to heat will expand and exert pressure. This pressure generated by the gas can be used to perform mechanical work.

This design allows for the difference in pressure between two reservoirs connected to a double acting hydraulic cylinder to move the collector depending on which reservoir is receiving more heat at that point in time.

A major parameter in the design of this tracking device is the Altitude Angle of the collector. This is largely affected by the declination which in turn depends on the day of the year. For this reasons, calculations of the altitude angle will be made for two specific days which are June 21st when the declination is 23.45^0 and September 21st when it is 0^0. The dimensions of the tracking device will be based on these days.

3.11 DESIGN CALCULATION

Initial Data	Calculation and Sketches	Results
	Declination calculation based on June 21st	
$L = 11^o$ $n = 172$ for 21 June	$D = 23.45\sin\left(\frac{360}{365}(284 + n)\right)$ $= 23.45\sin\left(\frac{360}{365}(284 + 172)\right)$ $= 23.45\sin\left(\frac{360}{365} \times 465\right)$ $= 23.45^o$	$D = 23.45^o$
	 **Fig 3.3 module at solar noon**	

Day min 15 3/20 21 X 22 5/3	**<u>Time correction for 21st June</u>** Correlation obtained from Data in solar energy by Donald Rapp 1981 $\frac{21-15}{22-15} = \frac{X - (^{-3}/_{20})}{^{5}/_{3} - (^{-3}/_{20})}$ $^{6}/_{7} = \frac{20X+3}{20}$ X = 1.4707	X = 1.41min
D = 23.45° L = 11° H = 0° at solar noon from equation 3.6A.	**<u>Altitude Angle at Solar noon</u>** using equation 3.1 $A = Sin^{-1}$ [CosDCosHCosL + SinDSinL] $=Sin^{-1}$ [Cos23.45°CosO°Cos11° + Sin 23.45oSin11°] $= Sin^{-1}$ [0.9174 x 1 x 0.9816 + 0.3979 x 0.1908] $= Sin^{-1}$ (0.9005 + 0.0759) $= Sin^{-1}$ (0.9764) = 77.533	A = 77.5°

At sunrise and sunset altitude angle is equal to 90° and close to the equator the sunrise would have completely gone over the horizon before sunset. Therefore the altitude angle at 2 hours after sunrise and 30 minutes before sunset will be used for the design calculation of the altitude angles

Longitude of location = 8^o Standard longitude of location = 15^o Time correction = 1.41min	**<u>Altitude angle at 0800hrs</u>** **<u>Local Apparent Time LAT</u>** From equation 3.6 B LAT = standard clock time + 4 (standard longitude – standard for clock time clock time) + Time correction Recall that LAT is negative in forenoon LAT = 0800hr – 4 (15 – 8) + 1.41min LAT = 0800hr – 28 + 1.41min = 0800hr – 26.59 min = 0700hr + (60 min – 26.59min) = 0700hr + 33.41 min = 0733.41hr = 0733hr 25 sec = 0734hrs = 7.34am	LAT = 7.34am

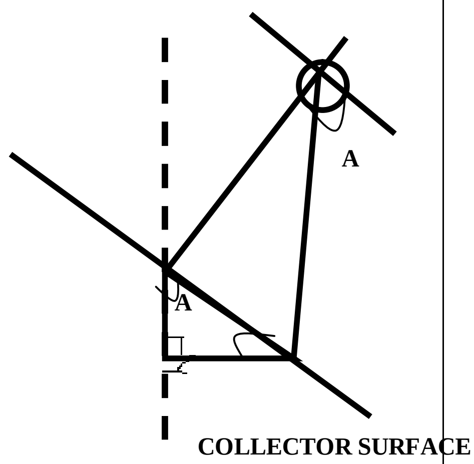


Fig 3.4 module at sunrise

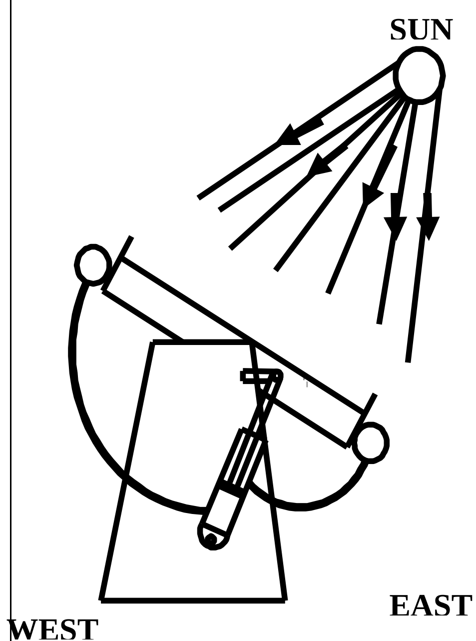
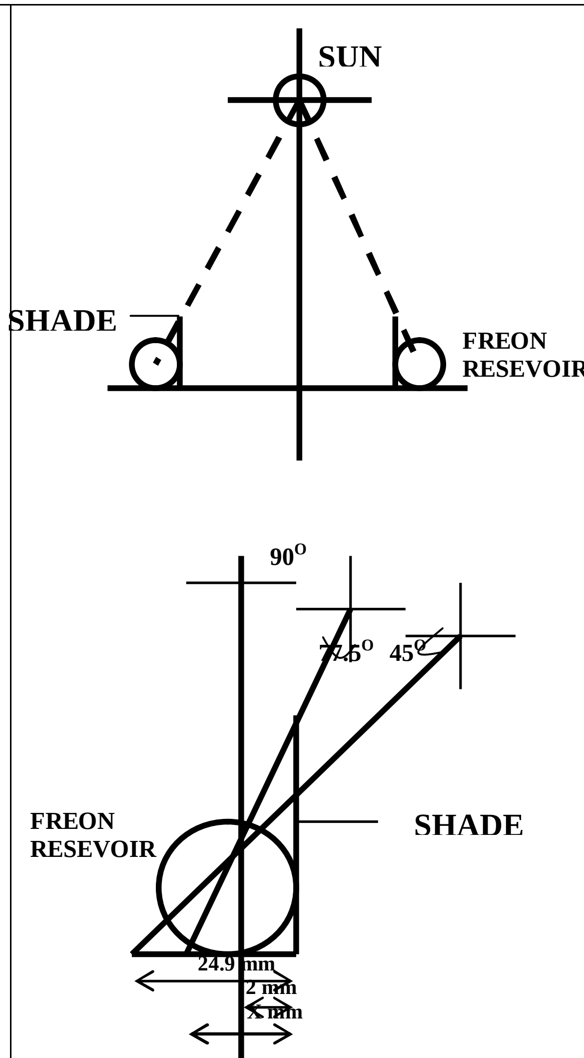


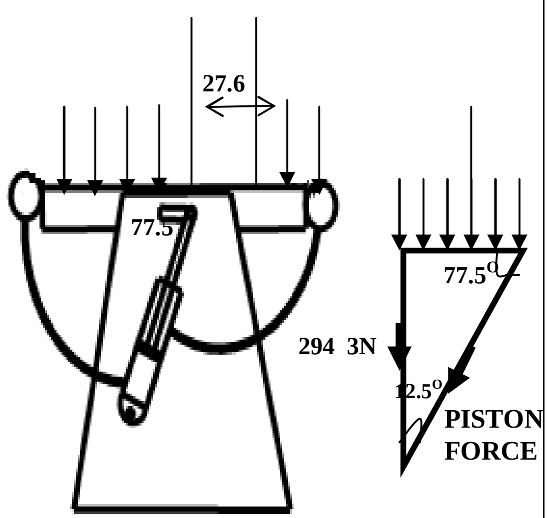
Fig 3.4 module at sunrise

Initial Data	Calculation & Sketches	Results
LAT = 0734	**<u>Hour Angle</u>** H = $(15t)^o$ From equation 3.6A T = 12 – LAT equation 3.6B H = 15 (12 – LAT) Recall that LAT is negative in fore noon H = -15 (1200 – 0734) = -15 {(11 – 7) hr = (60 – 34) mm} = -15 (4hr + 26mm) = -15 (4.43hrs) = -66.45^o	H = -66.45^o
D = 23.45^o L = 11^o H = - 66.45^o But Cos – 66.45 = Cos 66.45	**<u>Altitude Angle</u>** Sin A = CosDCosHCosL + SinDSinL = $Cos23.45^o Cos66.45^o Cos11^o$ + $Sin23.45^o Sin11^o$ = 0.9174 x 0.3995 x 0.9816 + 0.1908 x 0.3979 = 0.4356 A = $\sin^{-1}$ (0.4356) = 25.82^o	A = 25.82^o

Time correction = 1.41 min	**<u>Altitude Angle at 1730hrs</u>** **<u>Local Apparent Time LAT</u>** LAT = 1730hr – 4 (15 – 8) + 1.41 min = 1730hr – 28min + 1.41min = 1730hr – 26.59min = 1630hr + (60min – 26.59min) = 1630hr + 33.41min = 1703.41hrs = 1703hr 25sec = 1704hr = 5.04pm	LAT = 0504 hrs
LAT = 1704hr LAT is positive in the afternoon	**<u>Hour Angle</u>** H = 15 (1704 – 12) = 15 x 5.04hr = 76.05^o	H = 76.05^o

$D = 23.45^o$ $L = 11^o$ $H = 76.05^o$	**<u>Altitude Angle</u>** SinA = CosDCosHCosL + SinDSinL $= Cos23.45^oCos76.05^oCos11^o + Sin23.45^oSin\ 11^o$ = 0.9174 x 0.2411 x 0.9816 + 0.3979 x 0.1908 = 0.2930 $A = sin^{-1}\ (0.293)$ $= 17.04^o$	$A = 17.04^o$
Angle Base Length 45^o 25mm 77.5^o x mm 90^o 12.5mm	**<u>Base length of shades</u>** $\frac{77.5^o - 45^o}{90o - 45} = \frac{x - 25mm}{12.5mm - 25mm}$ X = 15.975 X = 16mm	X = 16mm
Base length (x) = 16 $A = 77.5^o$	**<u>Height of Shades</u>** $Tan\ A = \frac{height}{Base} = \frac{h}{x}$ $Tan\ 77.5 = \frac{h}{16}$ h = 16 x 4.51 = 72.17 = 72.2mm	h = 72.2mm

	 **Fig 3.5 shade hieght**	
T_{sc}= 380 x $10^6 N/m^2$ D_o = 0.0254m Wall thickness = 0.001m	**<u>Maximum Permissible Pressure in refrigerant reservoir</u>** Max press = <u>(max well thickness) x 2 (tensile strength)</u> Outer diameter of conductor $= \frac{1 \times 10^{-3} \times 2 \times 380 \times 10^{-6}}{25.4 \times 10^{-3}}$ = 29.92×10^6 N/m^2	Max press = 29.92×10^6 N/m^2

	<u>Permissible Pressure in Refrigerant Reservoir</u> (max working Pressure)	
Max press. $=29.92 \times 10^6 N/m^2$ Factor of safety $= 4$	Working pressure $= \frac{\text{max press}}{\text{factor of safety}}$ $= \frac{29.92 \times 10^6}{4}$ $= 7.48 \times 10^6 N/m^2$	$WP = 7.48 \times 10^6\ N/m^2$
m = 30kg $a = 9.81 m/s^2$ $A = 77.5^o$	**<u>Load on Hydraulic Cylinder</u>** **<u>Load on piston</u>** Load on piston = ma LF $= 30 \times 9.81$ $= 294.3N$ $\text{Sin } A = \frac{\text{Load Force}}{\text{Piston Force}} = \frac{LF}{PF}$ $PF = \frac{LF}{\text{Sin } A} = \frac{294.3}{\sin 77.5}$ $= \frac{294.3}{0.9763}$ $= 301.44N$  **Fig 3.6 load on piston**	LF = 294.3N PF = 301.4N

	Volume of Refrigerant Reservoir From equation 3.8 Volume of cylinder = Area x Length $V = \frac{\Pi d^2 L}{4}$ $= \frac{3.142 \times 0.0234^2}{4} \times 1.45$ $= 6.2 \times 10^{--4}\ m^3$	$V_{RR} = 6.24 \times 10^{-4}\ m^3$
Length = 152.4mm = 0.1524m Outer diameter = 43.78mm = 0.4378m Internal diameter = 38.1mm = 0.0381m	**Volume of Hydraulic Cylinder** Volume $= \frac{\prod d2}{4} \times L$ $= \frac{3.142 \times 0.0381^2}{4} \times 0.1524$ $= 1.73 \times 10^{-4}\ m^3$	$V_{HC} = 1.73 \times 10^{-4}\ m^3$

$P(27^oC)$ = 1304kg/m2 V_{HC} = 1.73 x 10^4m^3 V_{RR} = 6.24 x 10^4m^3	**<u>Mass of Refrigerant Required</u>** Volume of reservoir + ½ volume of hydraulic cylinder $= 6.24 \times 10^{-4}m^3 = \dfrac{1.73 \times 10^{-4}m^3}{2}$ $= 7.105 \times 10^{-4}m^3$ $\therefore$ mass of Refrigerant = Density x Volume $= 1304 \times 7.105 \times 10^{-4}$ = 0.93kg/Reservoir	m = 0.93kg/Rservior
b = 1520mm $A = 11^o$	**<u>Frame Construction</u>** **<u>Refer to drawing 3</u>** **<u>Triangle 1</u>** $a = 1520\cos 11^o = 1492.1mm$ = 1.49m $c = 1520\sin 11^o = 290.03mm$ = 0.29m	a = 1.49m c = 0.29m
b = 1520mm $A = 11^o$	**<u>Triangle 2</u>** $d = \dfrac{1520\sin 11^o}{\cos 11^o} = \dfrac{290.03}{\cos 11^o}$ = 295.46mm $f = d\sin 11^o = 295.46 \times 0.1908$ = 56.376mm	d = 0.296m f = 0.056m

e = 589	**<u>Triangle 3</u>** g = 589Tan11^o = 114.49mm h = $\frac{114.49}{\sin 11^o}$ = 600.02mm I = f + g + a = 0.115 + 1.492 + 0.056 = 1.663m = 1.66m (approx)	g = 0.115m h = 0.6m I = 1.66m

3.12 LENGTH OF THROW – ARM

The length of the “thrown Arm is a very important parameter in the design of the tracker for if a correct length is not determined, the tracker would not be able to track the sun fully at the calculated altitude angle for sun rise and sunset.

The length of the throw-arm is calculated based on the stroke of the hydraulic cylinder chosen and would be calculated at sunrise when the position stroke is approximately at its full length Inside the cylinder

The cylinder selected has a stroke of 152.4mm (6m inches)

A_1 = altitude angle at sunrise

= 25.82^o

A_2 = altitude angle at sunset

= 17.04^o

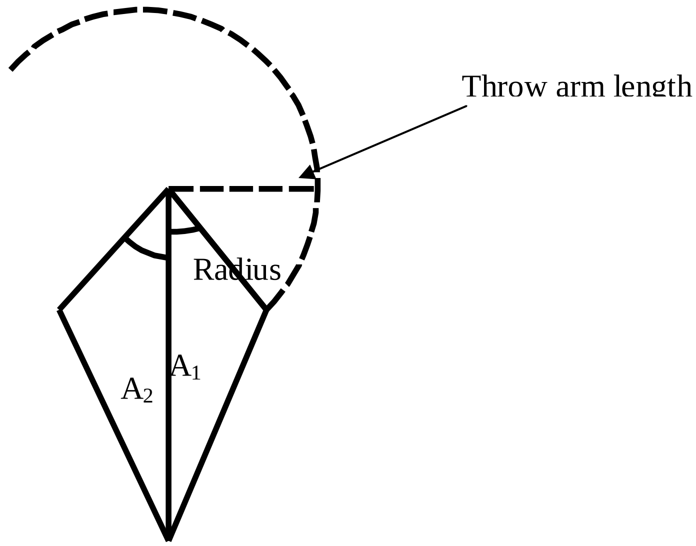


Fig3.7 Throw arm length

The total angle that the tracker would make will be the difference in the summation of the altitude angles at sunrise and sunset and the total angle subtended at the centre i.e. 360^o

Therefore the total angle made by the tracker = $360^o - (25.82^o + 17.04^o)$

$$= 360^o - 42.86^o$$

$$= 317.14^o$$

$$317.14^o = \frac{317.14 \times 2\prod}{360} = 5.53 \text{ radians}$$

But Arc length = Radius x Angle subtended.

Radius = Throw Arm length = $\frac{\text{Arc length}}{\text{Angle subtended}}$

$$= \frac{15.4}{5.53} = \underline{27.56\text{mm}}$$

3.13 HYPOTHETICAL PRESSURE GENERATED BY GAS IN RESERVIOR

From equation 3.10 and 3.11

$R = \frac{R}{M} =$

$R = \frac{8314.5}{120.91} = \quad 68.766$ Nm/KgK

And $PV = mRT$

$P \quad = \quad \frac{mRT}{V}$

If only 0.25Kg of the gas boils in the course of the day at an average temperature of 30^oC, the pressure generated will be

$P = \frac{0.25 \times 68.77 \times 303}{7.97 \times 10\text{-}4}$

$= \quad 6.536 \times 10^6\ N/m^2$

$=$ **6.536 Mpa**

3.14 ALTITUDE ANGLES AT OTHER DATES IN THE YEAR

March 21st

Altitude Angle at solar Noon $= 79^o$

Altitude Angle at 0800hr $= 23.82^o$

Altitude Angle at 1730hr $= 13.69^o$

September 21st

Altitude Angle at solar Noon = 79^{o}

Altitude Angle at 0800hr = 24.26^{o}

Altitude Angle at 1730hr = 12.50^{o}

December 21st

Altitude Angle at Solar Noon = 77.50^{o}

Altitude Angle at 0800hrs = 25.90^{o}

Altitude Angle at 1730hr = 16.86^{o}

3.15 HEIGHT OF SHADE REQUIRED ON SEPTEMBER 21ST AND MARCH 21ST

height h = 82mm(minimum)

Recall time correction for June 21 = 1.41 min

CHAPTER FOUR

CONSTRUCTION OF SOLAR TRACKER AND MATERIAL SELECTION

4.1 METHODOLOGY

The project was achieved by designing a single axis variable speed, passive solar tracker. This was accomplished by using 1.86kg of oiled Freon 12 filled, copper pipes to activate a double acting hydraulic cylinder. The Montreal Protocol declares that Chlorofluorocarbons destroys the protective layer of the atmosphere ie the Ozone layer and was named as one of the substances that has to be faced out of use, however it is still readily available and affordable. The oil used was Castor oil (Refrigeration compressor oil). This prevents the binding of rubber seals within the double acting hydraulic cylinder.

A solar module was placed on the tracker to receive the sun light as the device tracks the sun. Two electronic meters and a 5volt dc bulb was connected to the solar module. One meter read the current and the other the voltage in the system.

A control solar panel was also used which was oriented in a fixed directions north-south of the equator and the current and voltage recorded also.

The power (current x voltage) recorded for the tracking and stationary panels were then compared and the efficiency of the tracker calculated against the stationary one.

4.2 DESCRIPTION OF THE SOLAR TRACKING DEVICE

The solar tracking device consist of two vacuumed (copper) reservoirs (both painted black to increase the absorption of the sun's rays) of a low boiling point working fluid (Freon 12).The reservoirs are mounted one on each side of a pivoted solar collector (solar modules) and the two tanks are connected by Freon transfer hoses to a double acting hydraulic cylinder (one tank to one input on the cylinder and the second reservoir to the other output).

Each container of working fluid is shaded an equal amount so that when the sun moves across the sky the shadows from the shades will fall on one reservoir more than the other.

The ends of the copper pipes were sealed using oxyacetylene flames by welding flat copper plates at each end. A bicycle valve (Schroeder valve) was welded also by oxyacetylene flame to the copper pipes. The shades were attached to the base by electric spot welding while the frame was put together by a combination of oxyacetylene welding and use of bolts and nuts. The double acting hydraulic cylinder is mounted to the wall of the tracker using bolts and nuts also. The charging hoses are attached to the valve on the Freon -12 reservoir by screws that depress the Schroeder valve pin thereby allowing the flow of Freon 12 from the reservoir.

4.3 HOW THE SOLAR TRACKER WORKS

As the sun's appears on the eastern horizon (to the right) this causes the tank with the greater solar exposure to collect more heat and boil an increased amount of its working fluid. The difference between the higher pressure that this action creates in the warmed reservoir and the lower pressure maintained in the unwarmed reservoir works through the still liquid Freon-12 to either extend or retract the piston in the hydraulic cylinder. As a result, the movement of the piston (which is connected to the pivoted solar module through an eccentric arm) either pushes or pulls the solar absorption module into alignment with the sun.. As the sun rises in the East the next morning, the reservoir facing the sun begins to warm up and soon causes the module to face the rising sun and the process begins allover again.

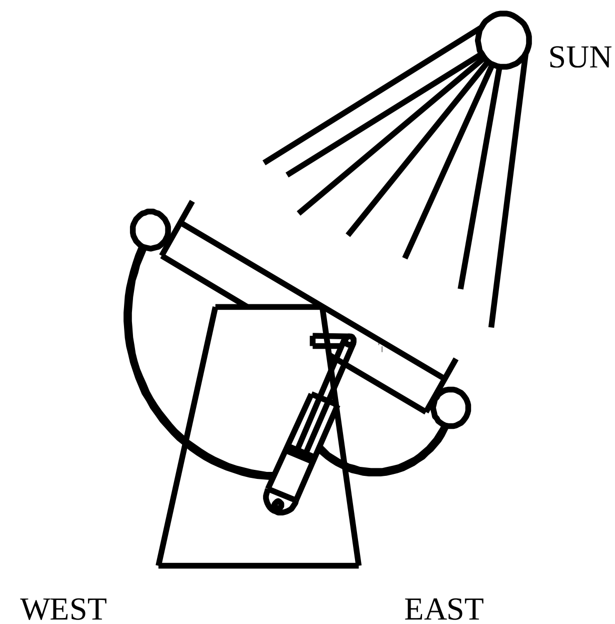


Fig 4.1 Tracker oriented to the sun at sunrise

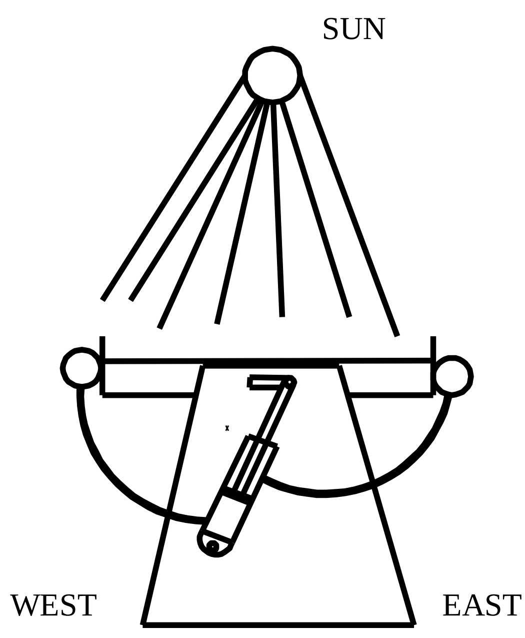


Fig 4.2 Tracker oriented towards the sun at noon

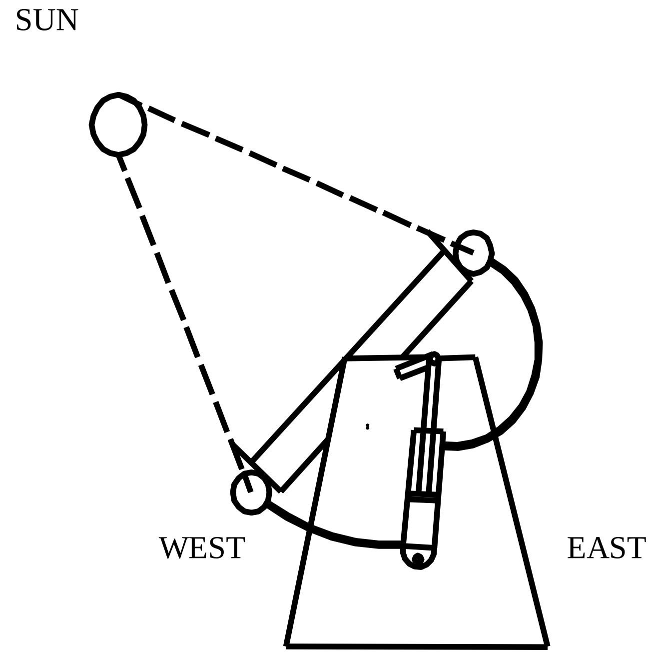


Fig 4.3 Tracker at sunset

4.4 <u>SPECIFICATION OF THE SOLAR TRACKING DEVICE COMPONENTS</u>

4.4.1 <u>The Refrigerant</u>: This expands on absorption of solar heat thereby moving the piston in the hydraulic cylinder in the direction of greater solar intensity. The required properties are:

a. Has a vapour pressure lower than atmospheric.

b. Should be able to build up a good head of pressure.

c. Should have good increase in pressure with change of state.

d. Should be non corrosive to the material in which it is contained.

e. Should be non poisonous.

4.4.2 Frame: This refers to the material used for the main body construction of the solar tracking device. The desired properties include:

a. Should be resistant to atmospheric corrosion.

b. Should be sufficiently heavy to be anchored to the ground.

c. Should be covered with protective coating.

d. Should be made of such material, as to permit ease of working or attachments.

e. The material should not be too affected by direct contact with ground and exposure to normal weather conditions

4.4.3 Double Acting Hydraulic Cylinder: This serves as the actuator to move the solar collector through the frame in the direction of sunlight. Its properties include:

a. Should be airtight.

b. Must be sensitive to pressure changes on either side of the pistons.

c. The material from which it is made should not be too affected by direct contact with or exposure to normal atmospheric condition; neither should it be affected by the Freon 12 content.

4.4.4 Shades: This serves to cast a shadow on the refrigerant reservoirs so as to vary the intensity of sunlight on each refrigerant reservoir in the course of the day. The material should be

a. Light

b. Weather resistant

c. Stiff.

4.4.5 Refrigerant Transfer Hoses. This allows for transfer of refrigerant between the refrigerant reservoir and double acting hydraulic cylinder. They should

a. contain fittings that automatically depress the valves, opening them as they are screwed onto the valves.

b. be able to withstand relatively high pressure

4.4.6 Valves This allows for the charging of the refrigerant into the refrigerant reservoir. It should be

a. Corrosion resistant.

b. Able to withstand relatively high pressures

c. Adaptable to the refrigerant transfer hose.

4.4.7. Refrigerant Reservoir: This acts as a storage for the refrigerant. It should be

a. Corrosion resistant

b. Have good heat transfer properties

c. Relatively economical

4.5 MATERIAL SELECTION AND MANUFACTURING PROCESS

4.5.1 Frame: The material chosen for this is 1mm galvanized sheet to carry the collector i.e. the collector base, while ¾ inch mild steel square pipes were used for the legs of the tracking device. This was assembled together by gas welding and the use of bolts and nuts.

4.5.2 Double Acting Hydraulic Cylinder: This is made from Aluminum. It should be able to generate a thrust force greater than 301.44N (page 28) to carry the load imposed upon it by the collector, collector base and the refrigerant reservoirs. It should also have at least a piston stroke of 152.4mm. The hydraulic cylinder is attached to the tracker wall by means of bolts and nuts. Half the quantity of the castor oil is poured into this cylinder before it is connected to the Freon reservoirs through the charging hoses.

4.5.3 Shades: The shades were constructed from mild steel. For maximum amount of sensitivity to sun movement, a shade height of 82mm is to be used based on the declination on 21st September. The shade length is 1.52m. The shades were electric spot welded to the tracker base.

4.5.4 Two Refrigerant Hoses: A hose which can withstand a pressure of 7.48mPa (1084.6Psi) is used. The fixtures on the local charging hoses are removed and fixed unto a hose of the same internal dimension as the ordinary charging hose but with higher pressure handling capability 13.79MN/m^2 (2000Psi), using a pressing machine.

4.5.5 Valves: The valves on each refrigerant reservoir must also withstand a working pressure of 6.54Mpa. (948Psi). A Schroeder valve which is only capable of withstanding about 1MN/m2 (145psi) was used. This however was suitable because the reservoirs were charged with the fluid at very low pressures. When the tracker is tracking, the valve pin is depressed, thus it is no more subject to the working pressure.

4.5.6 **<u>Refrigerant:</u>** The refrigerant is Dichlorofloromethane (Freon – 12). Freon 12 unlike water, which at sea level boils, (i.e., its vapor pressure exceeds atmospheric pressure) at 212^{o}F (100^{o}C) , Freon 12 boils at a somewhat lower temperature than -34.44^{o}C (-30^{o}F) To say it the other way Freon 12 poured out into a bowl and exposed to the atmosphere, will vaporize unless the temperatures are maintained below -34.44^{o}C. At any higher temperature it will simply boil away or evaporate into the atmosphere.

Freon 12 is commonly used in refrigerators, air conditioning circuits, spray cans etc. merely by keeping it bottled up inside heavy coils of tubing, pressure containers and other such “closed systems” when contained this way the Freon can build up pretty good head of pressure (423Kpa at 10^{o}C, 909Kpa at 37.8^{o}C, 1719Kpa at 65.6^{o}C, 2965Kpa at 93.3^{o}C etc.).

In a closed system, not all the Freon is required to boil (change from liquid to gas) in order for the pressure inside the system to rise in the dramatic way described. Depending on the size and shape of the system, the pressure inside the system can be raised 50 or more psi by the boiling of only a few drop of the trapped Freon.

Freon 12 was therefore chosen because:

a. It provides typical operating temperatures, enough pressure to operate the system in a very positive manner but not enough to burst any of the tracker components.

b. it is compatible with all other material used in the assembly.

c. It is non explosive and relatively non-toxic.

d. It is relatively cheap

e. Is easily available from any refrigerant shop.

f. Only part of it needs to boil to gas to generate pressures needed.

4.5.7 **Refrigerant Reservoir**: The refrigerant reservoir selected was a 25.4mm, thin-walled hard copper pipe. The total length for both reservoirs was 2.9m. This copper pipe will withstand a maximum pressure of 7.48Mpa. The pipe ends are sealed with copper plates using oxyacetylene welding. The valves were also welded unto the reservoir by oxyacetylene flame. The remainder of the castor oil was then shared equally between the two reservoirs after which the pipes were vacuumed and the charged with the Freon – 12. It should be noted that charging of the reservoirs was done by placing the reservoirs in a freezer to cool it so as to allow it take in the required amount of Freon 12 (1.86kg).

CHAPTER FIVE

EXPERIMENTS AND RESULTS

5.1 EXPERIMENTATION

The construction of the solar tracking device was carried out using the dimensions arrived at in chapter three as shown in Drawing 1. The tracker framework is made from Mild steel while the Freon reservoir is from thin walled, hard copper tubing. The double acting hydraulic cylinder is made from mild steel.

Experiments were carried out in Kaduna for four days i.e. 12, 24, 25 and 26 of September 2007.

5.2 AIM

The aim of the experiment was to test the relative performance of the tracking device by comparing the output of a solar module placed on the tracker to a stationary solar module. The relative performance of the solar module were assessed by

i. measuring the current through each module.

ii. Measuring the voltage through each module.

iii. Measuring the power produced by each module.

iv. Measuring the of the relative performance of the tracking module over the stationary module.

5.3 PROCEDURE

The tracking device was placed tilting southwards at an angle of 11^{o} with the Freon reservoirs at right angles to the rays of sunlight. The stationary solar module was also fixed at 11^{o} southwards.

Two meters were connected to each solar module. An ammeter was connected to each solar module in series to get the current readings while a voltmeter was connected in parallel to measure the voltage drop in the lamp connected also in series. The lamp rated at 12volts, 5 watts acted as the load for each module.

Readings of current and voltage was taken every 30mins. Since these readings were taken during the rainy season, it was unable to get the readings for beyond 4:00pm as it rained heavily or it became very cloudy. Solar module 1 was on the tracking device while solar module 2 was stationary.

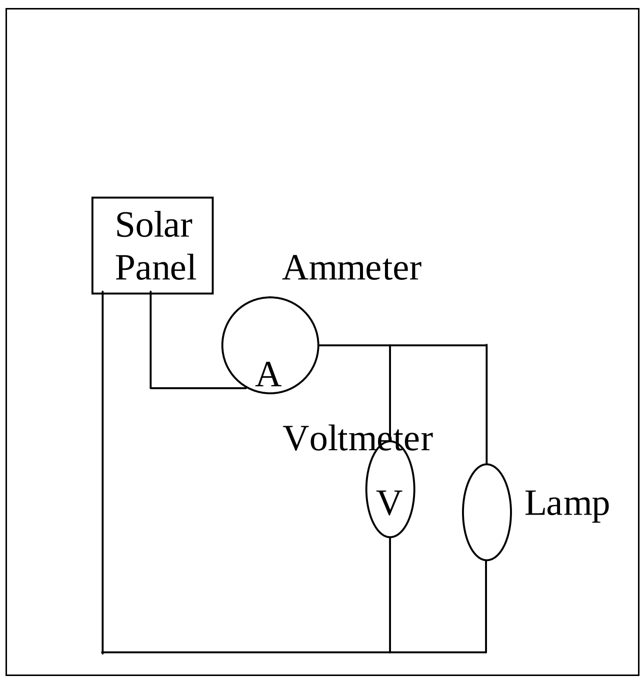


Fig 5.1 Electrical Connection of solar modules to Meters and Bulb

5.4 RESULTS

The results of the experiment are given in tables 1 - 4

Table 5.1 Measured Current, Voltage and Power

Day 1 12 – 09 – 07

Time	Tracking Solar Panel			Stationary Solar Panel		
	Current	Voltage	Power	Current	Voltage	Power
H(Hours)	I(Amps)	V(Volts)	P(Watts)	I(Amps)	V(Volts)	P(Watts)
07:00	0.1	2	0.20	0.03	1	0.03
07:30	0.14	2	0.28	0.07	1	0.07
08:00	0.24	3	0.72	0.13	1	0.26
08:30	0.33	5	1.65	0.2	2	0.04
09:00	0.41	6	2.46	0.27	3	0.81
09:30	0.37	5	1.85	0.24	3	0.72
10:00	0.43	7	3.01	0.37	3	1.11
10:30	0.45	8	3.60	0.4	6	2.40
11:00	0.45	8	3.60	0.44	7	3.08
11:30	0.45	8	3.60	0.44	7	3.08
12:00	0.45	8	3.60	0.44	7	3.08
12:30	0.45	8	3.60	0.44	7	3.08
13:00	0.45	8	3.60	0.44	7	3.08
13:30	0.44	8	3.52	0.44	7	3.08
14:00	0.43	7	3.01	0.43	7	3.01
14:30	0.42	6	2.52	0.42	6	2.52
15:00	0.38	5	1.90	0.38	5	1.90
15:30	0.33	5	1.65	0.33	5	1.65
16:00	0.27	3	0.81	0.22	2	0.44
16:30	0.22	2	0.44	0.2	1	0.20
17:00	0.2	2	0.40	0.16	1	0.16
17:30	0.18	2	0.36	0.15	1	0.15
Total			**46.38**			**33.95**

Relative Performance =

$$\frac{\text{Total power of tracking system} - \text{Total power of stationary system}}{\text{Total power of tracking system}} \times 100\%$$

$$\frac{46.38 - 33.95}{46.38} \quad x \quad 100\% = \quad 26.80\%$$

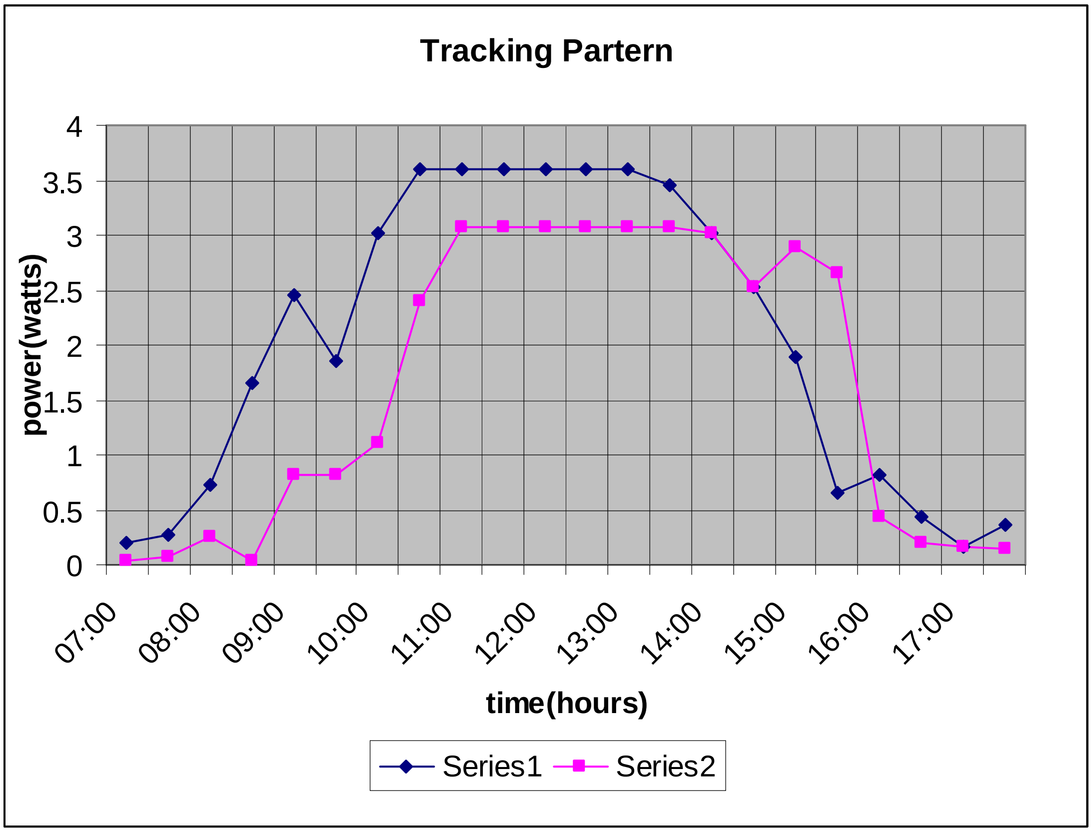


Fig 5.2 Power vs time for day 1

<u>Legend</u>

Series 1 - Tracking module
Series 2 - Stationary module

Day 2 **24 – 09 – 07**

Table 2 **Measured Current, Voltage and Power**

Time	Tracking Solar Panel			Stationary Solar Panel		
	Current	Voltage	Power	Current	Voltage	Power
H(Hours)	I(Amps)	V(Volts)	P(Watts)	I(Amps)	V(Volts)	P(Watts)
08:00	0.37	4	1.48	0.17	2	0.34
08:30	0.40	5	2.00	0.22	2	0.44
09:00	0.46	9	4.14	0.33	4	1.32
09:30	0.47	9	4.23	0.40	6	2.4
10:00	0.46	8	3.68	0.44	7	3.08
10:30	0.46	8	3.68	0.45	7	3.15
11:00	0.21	3	0.63	0.21	2	0.42
11:30	0.45	8	3.60	0.43	7	3.01
12:00	0.45	8	3.60	0.44	7	3.08
12:30	0.45	8	3.60	0.44	7	3.08
13:00	0.45	8	3.60	0.44	7	3.08
13:30	0.46	9	4.14	0.45	8	3.6
14:00	0.45	9	4.05	0.45	8	3.6
14:30	0.45	9	4.05	0.44	7	3.08
15:00	0.45	9	4.05	0.44	7	3.08
15:30	0.45	9	4.05	0.44	7	3.08
16:00	0.18	2	0.36	0.15	1	0.15
Total			**54.94**			**39.99**

Relative Performance = $\frac{54.94 - 39.99}{54.94}$ x 100% = 27.21%

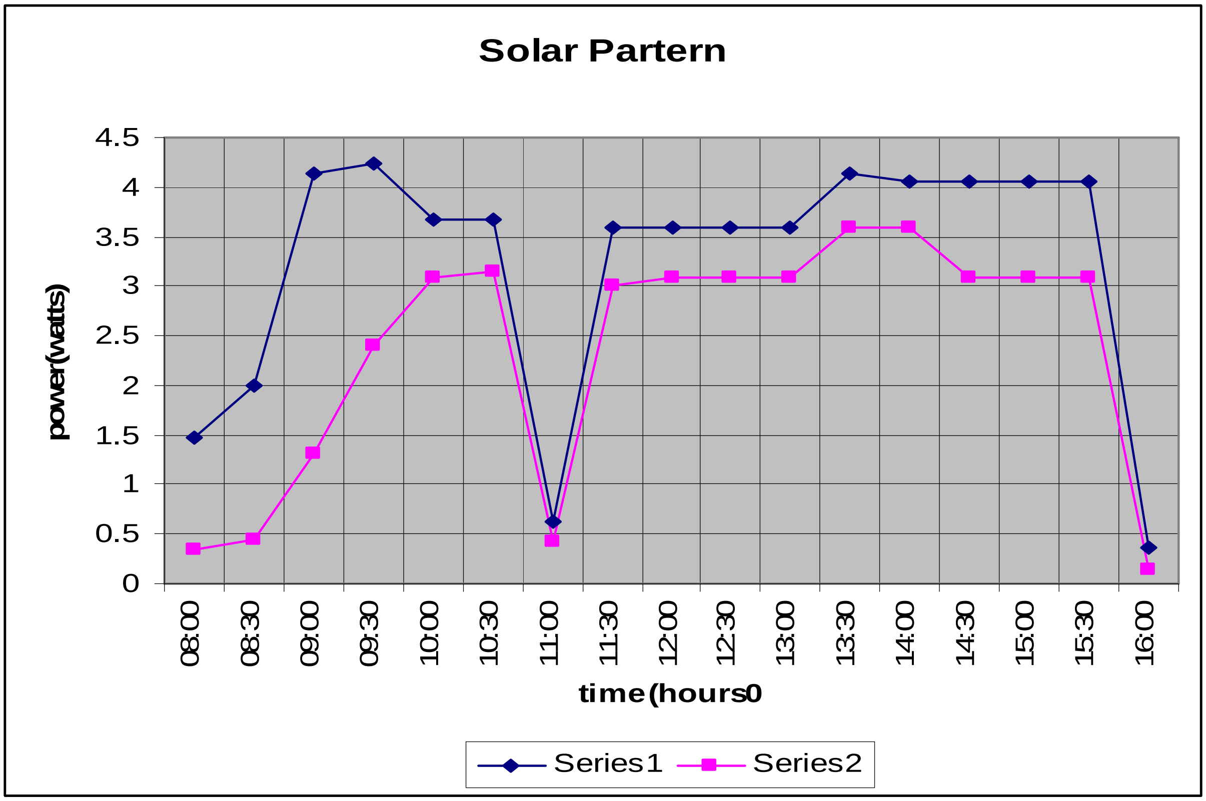


Fig 5.3 Power vs time for day 2

<u>Legend</u>

Series 1 - Tracking module
Series 2 - Stationary module

Table 3 Measured Current, Voltage and Power

Day 3 25-09-07

Time	**Tracking Solar Panel**			**Stationary Solar Panel**		
	Current	**Voltage**	**Power**	**Current**	**Voltage**	**Power**
H(Hours)	**I(Amps)**	**V(Volts)**	**P(Watts)**	**I(Amps)**	**V(Volts)**	**P(Watts)**
07:00	0.04	1.00	0.04	0.03	1.00	0.03
07:30	0.28	2.00	0.56	0.10	1.00	0.10
08:00	0.37	4.00	1.48	0.17	2.00	0.34
08:30	0.40	5.00	2.00	0.22	2.00	0.44
09:00	0.43	7.00	3.01	0.29	3.00	0.87
09:30	0.45	8.00	3.60	0.40	6.00	2.40
10:00	0.45	8.00	3.60	0.42	7.00	2.94
10:30	0.44	8.00	3.52	0.42	7.00	2.94
11:00	0.44	8.00	3.52	0.43	7.00	3.01
11:30	0.44	8.00	3.52	0.43	7.00	3.01
12:00	0.43	8.00	3.44	0.41	6.00	2.46
12:30	0.44	8.00	3.52	0.43	7.00	3.01
13:00	0.45	8.00	3.60	0.44	7.00	3.08
13:30	0.46	8.00	3.68	0.45	7.00	3.15
14:00	0.45	8.00	3.60	0.44	7.00	3.08
14:30	0.45	8.00	3.60	0.42	6.00	2.52
15:00	0.44	8.00	3.52	0.41	6.00	2.46
15:30	0.40	7.00	2.80	0.32	4.00	1.28
16:00	0.31	5.00	1.55	0.21	3.00	0.63
16:30	0.05	2.00	0.10	0.04	2.00	0.08
Total			**54.26**			**37.83**

Relative Performance = $\frac{54.26 - 37.83}{54.26}$ x 100% = 30.28%

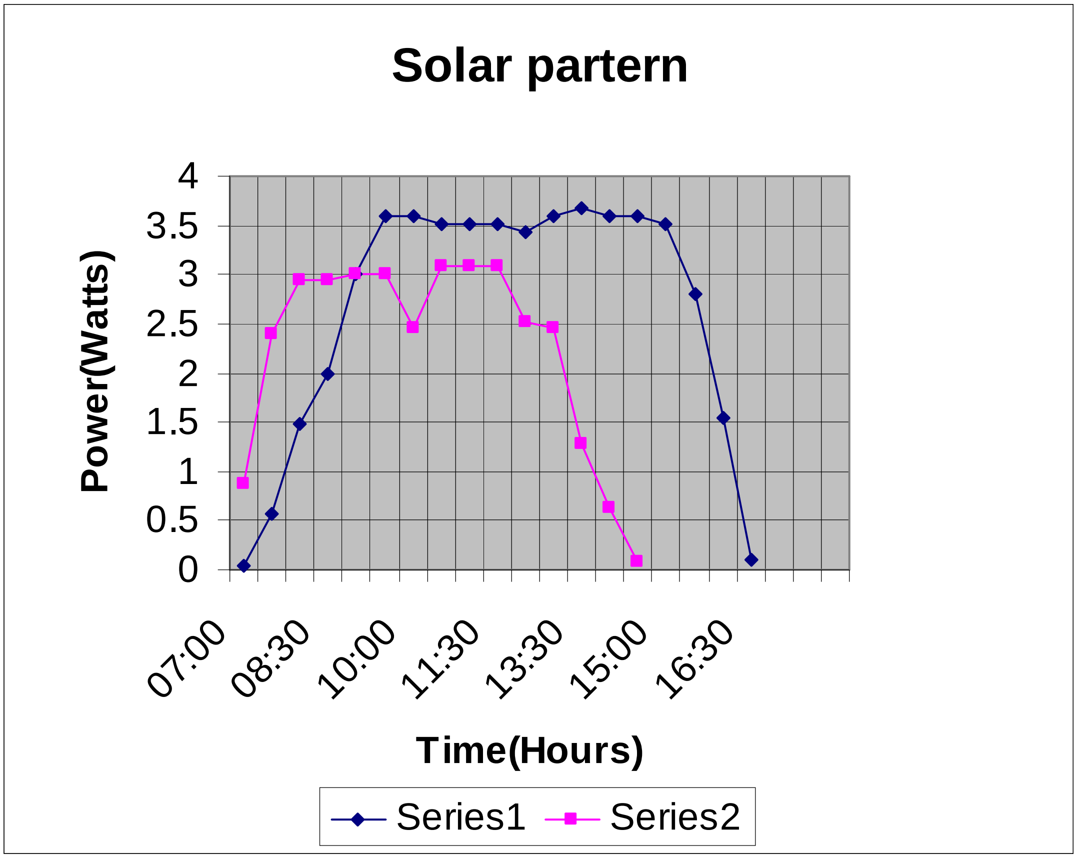


Fig 5.4 Power vs time for day 3

<u>Legend</u>

Series 1 - Tracking module
Series 2 - Stationary module

Day 4 **26-09-07**

Table 4 **Measured Current, Voltage and Power**

Time	Tracking Solar Panel			Stationary Solar Panel		
	Current	Voltage	Power	Current	Voltage	Power
H(Hours)	I(Amps)	V(Volts)	P(Watts)	I(Amps)	V(Volts)	P(Watts)
07:00	0.01	1.00	0.01	0.01	1.00	0.01
07:30	0.07	1.00	0.07	0.07	1.00	0.07
08:00	0.35	5.00	1.75	0.24	2.00	0.48
08:30	0.31	5.00	1.55	0.22	2.00	0.44
09:00	0.46	8.00	3.68	0.39	5.00	1.95
09:30	0.47	8.00	3.76	0.4	6.00	2.40
10:00	0.45	8.00	3.6	0.41	6.00	2.46
10:30	0.45	8.00	3.6	0.42	7.00	2.94
11:00	0.45	8.00	3.6	0.44	7.00	3.08
11:30	0.45	8.00	3.6	0.44	7.00	3.08
12:00	0.45	8.00	3.6	0.44	7.00	3.08
12:30	0.44	8.00	3.52	0.44	7.00	3.08
13:00	0.44	7.00	3.15	0.43	6.00	2.58
13:30	0.44	7.00	3.15	0.43	6.00	2.58
14:00	0.44	7.00	3.15	0.42	6.00	2.52
14:30	0.44	7.00	3.15	0.4	6.00	2.40
15:00	0.44	7.00	3.15	0.4	6.00	2.40
15:30	0.42	7.00	2.94	0.31	4.00	1.24
16:00	0.39	7.00	2.73	0.24	2.00	0.48
16:30	0.37	6.00	2.22	0.18	2.00	0.36
17:00	0.31	4.00	1.24	0.13	1.00	0.13
17:30	0.21	2.00	0.42	0.08	1.00	0.08
Total			**57.64**			**37.84**

$$\textbf{Relative Performance} = \frac{57.64 - 37.84}{57.64} = \frac{19.8}{57.64} = 34.35\%$$

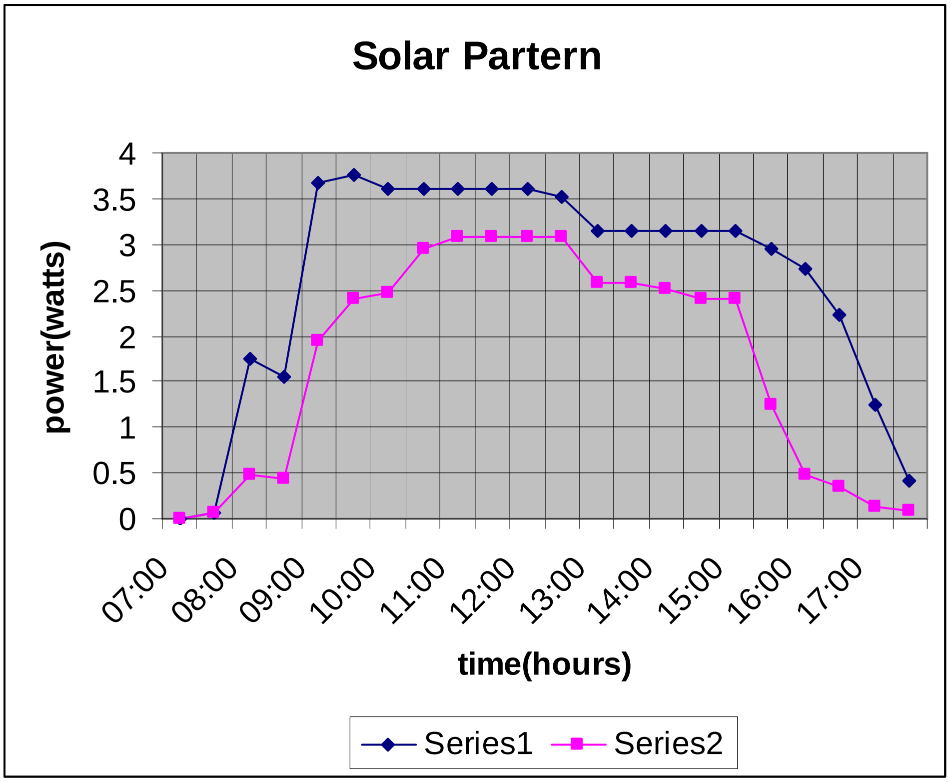


Fig 5.5 Power vs time for day 4

Legend

Series 1 - Tracking module
Series 2 - Stationary module

$$\textbf{Average Relative Performance} = \frac{\text{Total Performance over the Days}}{\text{Number of days}}$$

$$\textbf{Average Relative Performance} = \frac{26.80 + 27.21 + 30.28 + 34.35}{4} = \frac{118.64}{4}$$

$$= 29.66\%$$

5.5 DISCUSSION

Figures 5.2 to Figure 5.5 shows relative performances of 26.8%, 27.21%, 30.28% and 34.35%.The average relative performance for the tracking device was calculated to be 29.66%. This percentage is in agreement with published experimental data of 30%.(Arinze et al., 1988). There was no lag time observed between the sun movement and the tracker. The dips observed in the graphs were periods when the sun was completely overcast by clouds. The figures also suggest that the maximum power difference between the tracking module and the stationary module occur at about 9:30 am and 4:30 just before the sun is directly overhead the location and after it is overhead the location respectfully

Plate 1:

Tracker at 9:00am (front view)

Plate 2:

Tracker at 9:00am (end view)

Plate 3: tracker at 11:45am

Plate 4: Tracker at 1:00pm

Plate 5: Tracker at 3:00pm

Plate 6: ammeter and voltmeter for tracking and stationary panels

5.6 <u>COSTING</u>

Solar Modules	Qty 2	=	N 40, 000
Hydraulic Cylinder		=	N 30, 000
1mm thick Galvanized Sheet for Collector Base		=	N 3, 000

3mm thick Mild Steel for Hydraulic Cylinder	=	N 500
20 Feet of ¾" Square Pipe	=	N 1, 500
Nuts and Bolts	=	N 500
Bicycle/Refrigerator Charging Valves Qty	=	N 200
2 Ammeters and 2 Voltmeters	=	N 2, 000
2 Pressure Gauges	=	N 5, 000
Adaptors for Cylinders	=	N 2, 000
4 kg of Freon Gas	=	N 5, 000
2 no Freon transfer Hoses	=	N 5, 000
10 Feet thin walled, Hard Copper Pipes	=	N 2,000
Compressor Oil	=	N 500
Labour	=	N 5, 000
Miscelaneous	=	N 5, 000
Total		**N 107, 200**

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1. CONCLUSION

The aim of the project has been achieved. The system is relatively simple and the materials used are available and can be fabricated with available equipment

The higher power harnessed by the tracking device confirms the fact that tracking is one of the ways of optimizing energy production of solar collectors. An average relative performance of 30% was obtained from tracking the sun. Cost comparison of the imported tracker of similar panel capacity showed that an imported one will cost about S900 (N112,500), apart from the cost of importation as against my locally fabricated one of approximately N70,000 without the solar modules.

6.2. RECOMMENDATION

The height of the shades could be increased to achieve more sensitive tracking of the sun as it was observed from the experiment that a shade height of 82mm using a declination on 21 September gave a more sensitive reaction than that of 72mm for June 21st.

The hydraulic cylinder used must also be oiled with compressor oil to avoid the binding of the rubber seals within the hydraulic cylinder. This is achieved by putting half of the castor oil directly into the double acting hydraulic cylinder and the other half into the copper reservoirs.

The copper reservoirs must also first be vacuumed to relieve it of all air before charging with Freon 12.

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