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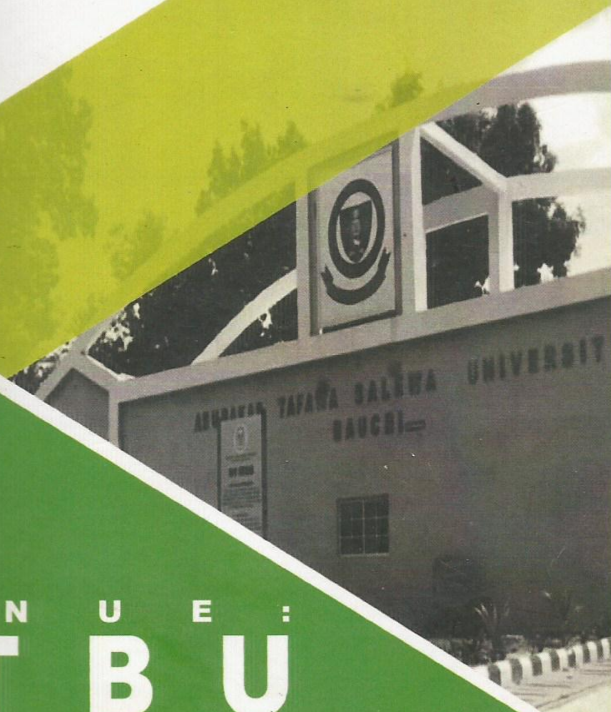

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DEVELOPMENT OF SOLAR ENERGY CLOTH IRONING SYSTEM AND TEST

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ABSTRACT

Charcoal is mainly used in the ironing of clothes in the rural areas. This is non-renewable use of energy resource areas. To replace this non-renewable energy source, there is need to develop a solar cloth ironing system. The iron received its heat from concentrated parabolic reflective dish. The design of the iron was based on the mass of aluminium required to be heated to a temperature of 155 °C in a period of 30 minutes. The sad iron was thereafter casted from a melt of 2.36 kg of aluminium to produce the sad iron according to the designed pattern. Temperature readings of the heated sad iron were taken for a period of eight months. The readings for the first three months (January to march, 2017) were taken from 8:00 am to 5:00 pm. Readings from these first three months established that the maximum sad iron temperature readings was at 2:00 pm. Hence, sad iron temperature readings from April to August were taken from 8:00 am to 2:00 pm daily. Readings of time taken of when sad iron was used to iron clothes were also taken from April to May on daily basis as from 2:00 pm. Considering from the economic point of view, the study shows that aside the initial cost of purchase of the sad iron, the sad iron was used at no cost to iron clothes for the subsequently. This work therefore established yet another dimension in the utilisation of solar energy domestically in Nigeria.

Introduction

Metal pans filled with hot coals were used for smoothing fabrics in China in the 1st century BC (Oldandinteresting.com. 2002). From the 17th century, sadirons or sad irons (from an old word meaning solid began to be used. They were thick slabs of cast iron, delta-shaped and with a handle, heated in a fire. These were also called flat irons. A later design consisted of an iron box which could be filled with hot coals, which had to be periodically aerated by attaching a bellows. In Kerala in India, burning coconut shells were used instead of charcoal, as they have a similar heating capacity. This method is still in use as a backup device, since power outages are frequent. Other box irons had heated metal inserts instead of hot coals (IELS, 1990).

Among the various types of clean and renewable sources, solar energy appears to be the most favourable option because of its infinite and non-polluting nature. According to Babalola (2012), solar energy is an ideal alternative source of energy because it is abundant and inexhaustible.

In Nigeria, the development strategies and efforts has been more urban based resulting in the relative neglect of rural areas as evidenced by the death of basic infrastructure in rural areas such as: good roads, electricity, etc. As a result of this, not all communities or rural areas are connected with grid and not every person can afford generator or charcoal. Where rural areas are connected with grid the function are epileptic, sun (solar energy) been a free gift from God can be used by all and the local iron can be easily avoidable (Nwokoye & Ike, 2003), (Adejumobi, *et al.*, 2011).

This work is aimed at developing direct solar heating cloth ironing system. This will be achieved by determining how much heat is obtainable from (available solar reflector) which will lead to the determination of appropriate mass of sad iron. Thereafter casting of the solar sad iron and test. From the test data there will be economic comparison of the developed sad iron with existing charcoal and electricity pressing irons.

General Climate of Nasarawa

Nasarawa is located in Nasarawa state at latitude of 8° 31' 45" N and longitude of 7° 43' 27" E. The town is characterized by a tropical sub-humid climate with two distinct seasons. The wet season begins around May and ends in October and the dry season is between November and April. Most of the rain falls between May and September, with the wettest month being July and August. Here, the rain comes with thunderstorms of high intensity especially at the beginning and end of the rainy season. Temperatures are generally high at daytime especially between the months of March and April (Adesina et al., 2015).

The Parabolic Solar Reflector

Geometrically, a parabola is a locus of points that lie on equal distance from a line (directrix) and a point (focus) (Figure 1). For each point of the parabola, DR = FR. The distance VF between the vertex and focus of the parabola is the focal distance (F). The line perpendicular to the directrix that passes through the focus is the axis of the parabola; the axis divides the parabola into two parts that are symmetrical (Morling, 2010).

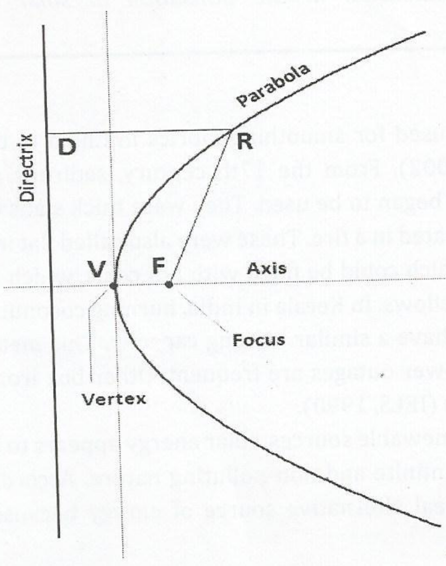

Figure 1: Geometry of the parabola
Source: (Morling, 2010)

By definition of the focal point of the parabola, all incoming rays parallel to the axis of the parabola are reflected through the focus. This provides an opportunity for light concentration by using parabolic surfaces. If we assume that solar light arrives to the surface as essentially parallel rays, and apply the Snell's law (the angle of reflection equals the angle of incidence), (Wolf, 1995), we can assign the focal point as an ideal location for the receiver (Kumar, *et al.*, 1995).

MATERIALS AND METHODS

Selection of Materials

The selection of materials includes the following four fundamental factors:

i. Availability of material
ii. Suitability of material for the working condition in service
iii. The cost of material
iv. The properties of a material

Table 1 below described properties and choice of materials in preference to application area.

Table 1: Materials Selection

S/N	Materials	Properties	Remark
1.	Mild steel	It is ductile & malleable. It is tough and can be hardened and tempered. Carbon content of 0.08-0.35% and melting point is 1400 C. It has strength and can absorb shocks It can be readily forged and welded.	Mild steel sheet was used for the Parabolic reflector base, guard & Boaster base. Mild Steel angle iron was used for the entire frames and the stand.
2.	Glass mirror	High reflectance/transmittance and optical performance compared with other reflective materials (Aluminium & silver mirror 82-98% reflectance) Resistance to degradation, good secularity [≤ 2mrad (0.10 degree)], durability and resistance to distortion from loads. High density and brittle Mirrors are used mostly in such solar thermal systems/subsystems as	A glass mirror was used for the reflector (Parabolic).

		parabolic troughs, parabolic dishes, spherical bowls, and heliostats.	
3.	Aluminium	Aluminium is ductile and malleable with a melting point of about 650 °C. High resistance to corrosion. Specific gravity, melting and boiling point are 2.7, 6580 C and 20570 C respectively. It is good conductor of heat and electricity. It is tensile varies from 95-157 MN/m².	Used to cast the sad iron
4.	Digital stop watch	High precision stop watch to measure time	Used for the measurement of Sad iron heating and cloths ironing periods
5.	Reference thermometer	ETI 222-005 Reference Thermometer with a metallic part inserted into the sad iron to take internal temperature of the iron. The range of the thermometer is –10°C and 300°C.	Temperature measurement of the sad iron

Description of the solar ironing system

The solar cloth ironing system is a method of ironing clothes where the iron used in ironing the clothes generates its energy from sunlight. This comprises mainly of the solar sad iron and the parabolic reflective dish. The sad iron is placed on the focal point of the parabolic reflective dish for solar heating.

Sad pressing iron

The sad pressing iron is similar to the local charcoal iron in domestic use and is made up of casted aluminium. To ensure low rate of heat transfer from the iron while ironing clothes, the iron was casted blunt without being hollow. Although this equally has the demerit of slow heating period compared to the normal charcoal iron in use, but the merit of its heat retaining ability counts more here. This is as shown in figure 2 below.

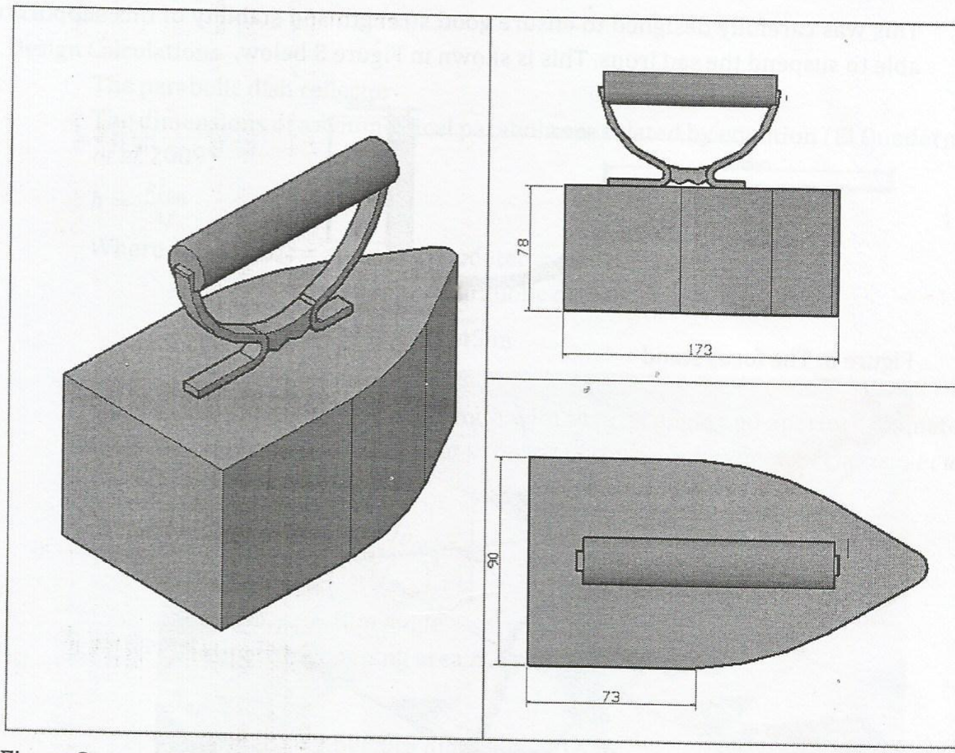

Figure 2: **The Fabricated sad Iron** (All dimensions in mm)

Parabolic solar dish

The parabolic dish used was adopted from a commercially available, satellite dish of aperture diameter. Da = 600 mm and height H= 50 mm. Thereafter, the focal length was determined to get the sun spot of the dish after adding the reflective surfaces.

The Reflector

The reflector surface is an arrangement of parabolic mirror designed to concentrate radiant energy from the sun at the focal point of the parabolic dish. This was achieved by cutting flat mirror into smaller shapes and thereafter glued to the parabolic dish.

The focus stand

The focus stand was made of half inch hollow rectangular pipe of mild steel material. This part provided the support for the sad iron to be centred at the focus of the parabolic reflector. One end of the stand was connected to the reflector and the other to the stand of the sad iron.

This was carefully designed to ensure good strength and stability of this support to be able to suspend the sad irons. This is shown in Figure 3 below.

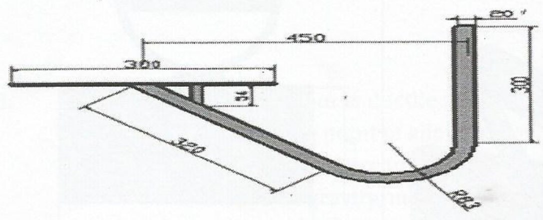

Figure 3: The focus stand

Plate I: Assembled Picture of the Project on site

METHODS

Design Calculations

The parabolic dish reflector

The dimensions of a symmetrical parabola are related by equation (El Quedermi, *et al*, 2009)

$$h = \frac{R_{rim}^2}{4f} \qquad 1$$

Where D_{ap} = aperture diameter = 600 mm = 0.6 m

h = depth of the parabolic dish = 50 mm = 0.05 m

$$\therefore f = \frac{0.6^2}{16\times0.05} = 0.45 \text{ m}$$

f = 0.45 m

The relationship between focal length with the rim angle and aperture diameter of the parabolic dish can be found in terms of the dish dimension (Yahuza, *et al.*, 2016).

$$\varphi_{rim} = tan^{-1}\left[\frac{8f/D_{ap}}{16\left(f/D_{ap}\right)^2 - 1}\right] \qquad 2$$

Where φ_{rim} = Rim angle

The aperture opening area A_{ap}:

$$A_{ap} = \frac{\pi D_{ap}^2}{4} \qquad 3$$

Where D_{ap} = Aperture diameter = 0.6 m

h = 0.05 m

$$\varphi_{rim} = tan^{-1}\left[\frac{\left(\frac{8\times0.45}{0.6}\right)}{16\left(\frac{0.45}{0.6}\right)^2 - 1}\right] = tan^{-1}\left(\frac{6}{8}\right) = 36.87^{\circ}$$

$\varphi_{rim} = 36.87^{\circ}$

The aperture opening area, A_{ap}

$$A_{ap} = \frac{\pi D_{ap}^2}{4}, \text{ where } D_{ap} = 0.6 \text{ m},$$

$$A_{ap} = \frac{3.124\times0.6^2}{4} = 0.2827 \text{ m}^2$$

Calculations involving solar radiation

The extra-terrestrial solar radiation in Nigeria can be calculated as given by (Folaranmi, 2009).

$$R_X = I_{XC}A_{CL} \qquad 4$$

Where R_X = Extra-terrestrial radiation?

I_{xc} = solar constant = 1353 kWh

A_{CL} = continental area = 9.3277 x 10^{11}

$\therefore R_X = 1353 \times 9.3277 \times 10^{11} = 1.262 \times 10^{15} Wh/m^2$

$R_X = 1.262 \times 10^{15} Wh/m^2$

For an average of nine hours of bright sunshine hours

$R_X = 9 \times 1.262 \times 10^{15} = 1.1353 \times 10^{16}\ W/m^2$

Expected power from the parabolic reflector

The expected power from the parabolic reflector is given by (Yahuza, *et al.,* 2016): - $Q_C = I_{XC} \times A_{ap}\rho$ 4

Where I_{XC} = solar constant = 1353 kWh (Yahuza, *et al.,* 2016)

A_{ap} = aperture opening area = 0.282 m²

ρ = reflectance of the mirror = 0.98 (Yahuza, *et al.,* 2016)

$\therefore Q_C = 1353 \times 0.2827 \times 0.98 = 374.843\ W$

$Q_C = 374.843\ W$

Mass of the Sad iron

By the definition of specific heat capacity, when the temperature of an object increases, it has gained energy (RevisionScience, 2018). The amount of energy depends on: -

- The temperature change, T
- The mass of the object, m
- The specific heat capacity, c

The specific heat capacity is different for different materials. It is the energy needed to increase the temperature of 1 kg of the material by 1°C and is measured in J/kg °C.

Since Energy = mass × specific heat capacity × temperature change 5

That is; E = m × C × T 6

Also, Energy supplied, E = power × time 7

That is; E = W x t

Equating equations 5 and 7 gives equation 8 below

$$m = \frac{t \times W}{C \times T} \quad 8$$

m = mass of aluminium to be moulded to form the sad iron

W = Power supplied to the sad iron from the parabolic dish = 374.843 W

Since, the efficiency range of most solar concentrators is 40% - 60% (Magal, 1993);

Taking 50 % efficiency, W = 187.4215 W

C = Specific heat capacity of aluminium = 921.096 J/kg/K

T = required temperature to iron cloth = 155 °C

t = time taken to heat the iron to the required temperature = 30 minutes

$$So, m = \frac{30 \times 60 \times 187.4215}{921.096 \times 155} = 2.36\ kg$$

From the above, the mass of the sad iron to be moulded for this work is designed to be **2.36 kg.**

Casting Process

Metal casting is the process in which molten metal is poured into a mould and allowed to solidify into an object. The object that results from this process is also called a casting.

Patternmaking: This is the first step in sand casting. The pattern is a replica of the exterior of the casting with dimensional allocation for shrinkage and finishing. The dimension used was that of an existing charcoal pressing iron.

Moulding: Moulding is a process that consists of different operations essential to develop a mould for receiving molten metal. This was achieved by packing sand around the pattern of the sad iron.

Melting and Pouring: Melting is a process of preparing the molten material for casting. This was carried out by heating the aluminium scraps to a temperature of 650 °C. The molten metal was transported to the pouring area to fill the cavity created in the mould by the sad iron pattern.

Cleaning: this was the last step which involved cleaning off unnecessary parts from the casted iron

RESULTS AND DISCUSSIONS

Temperature readings of the sad pressing iron

The sad iron was placed on the focus stand of the parabolic dish reflector with the base of the iron in direct contact of the focal point of the sun intensity. The base where the iron was placed is adjustable to enable up and down movement of the iron. Also, the reflective dish has its adjustment in tracking to keep the bright spot onto the centre of the bottom of iron.

The temperature reading was taken using the digital reference thermometer whose temperature sensor was inserted into the drilled hole of the sad iron. This was carried out on hourly basis from 8 am to 5 pm from the months of January to March 2017. While from the months of April to June, the readings were taken from 8 am to 2 pm. This was so because most of the highest temperature readings of the iron was obtained at about 2 pm in the previous months of readings.

After taking the highest temperature readings of the day, the sad iron was then used to iron clothes experimentally to obtain cooling temperature readings.

Table 2: The Average Hourly Monthly Temperature Readings of the Sad Iron

Time/Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug

8.00 AM	36.25	34.04	34.65	35.7	35.7	31.65	31.72	61.77
9.00 AM	41.3	40.58	41.58	40.35	40.84	35.16	34.7	67.54
10.00 MA	49.29	46.82	48.2	46.54	47.52	37.71	39.17	70.86
11.00 AM	57.36	55.76	56.67	51.74	53.75	40.37	42.3	78.39
12.00 PM	69.14	64.39	65.41	57.15	59.52	43.14	44.5	84.7
1.00 PM	81.19	72.42	74.21	65.48	63.86	45.23	45.9	90.07
2.00 PM	121.4	110.8	123.36	97.43	95.98	47.84	48.45	141.47
3.00 PM	113.66	101.18	95.56					
4.00 PM	101.04	91.25	110.16					
5.00 PM	91.04	83.08	83.68					

Table 2 above showed the average hourly monthly temperature readings of the sad iron. For the months of January, February and March, readings were taken on daily basis from 8:00 am to 5:00 pm. While for April, May, June July and August, readings were recorded on daily basis from 8:00 Am to 2:00 pm. These readings were terminated at 2:00 pm in the last five months to enable the optimum utilization of the highest temperature readings of the sad iron.

Procedure for test

As soon as the temperature reaches the peak of the day, it was quickly taken to a room for ironing. The fabric ironed depended on the temperature reading obtained. Readings were recorded of the fabric material in terms of cotton percentage, also, the time taken to iron a certain cloth was equally taken in seconds with the aid of a stop watch as recorded. The readings were taken in a range of temperatures in accordance to the fabric materials.

Table 3: Classification of Fabric According to Temperature Range and Ironing Time (S) for the Months of April and May

			April		May	
Average Temp. (°C)	**Temp. range (°C)**	**Fabric Material**	**Ironing time (s)**	**Final Temp. (°C)**	**Ironing time (s)**	**Final Temp. (°C)**
84.5	80-89	100% Light cotton	353.19	73.8	332.21	74.2
94.5	90-99	100% Light cotton	343.25	86.4	340.15	85.3
104.5	100-109	55% cotton, 45% polyester	370.66	92.8	383.2	96.2

114.5	110-119	Light Veritable wax (100% cotton)	310.21	90.3	330.1	91.4
124.5	120-129	veritable wax (100% cotton)	358.26	95.8	347.12	93.2
134.5	130-139	veritable wax (100% cotton)	373.41	99.3	392.05	95.4
144.5	140-149	100% polyester	483.45	111.8	490.17	110.3
154.5	150-159	Guaranteed Hitaget wax (100% cotton)	678.77	103.5	685.4	104.2

Table 3 above shows the observed time taken to iron different fabric materials at the grouped temperatures for the months of April and May 2017. Recorded was also the final temperature of the sad iron after each ironing process.
From the results in the table above, it was observed that the higher the temperature, the more the ironing period but depending on the fabric material.
For the first three of 100% Light cotton, and 55% cotton, 45% polyester fabric materials, whose average ironing temperatures were respectively 84.5 °C, 94.5 °C and 104.5 °C, the ironing time recoded were 353.19s, 343.25s and 370.66s. This shows a direct proportion of ironing temperature and ironing time. Also, when the fabric material was changed to veritable wax (100% cotton) and Guaranteed Hitaget wax (100% cotton) the above trend was still observed with ironing period directly proportional to the average temperature of the iron as shown in the table.
But there was a contradiction of this trend between the temperatures of 104.5 °C and 114.5 °C as against recoded periods of 370.66s and 310.21s respectively. This can be attributed to the change of fabric materials.

Cost comparison

The following procedures were taken to compare the cost of using the fabricated sad iron to other forms of ironing clothes. Electric iron was used to iron clothes for an equal period of time as being done by the sad iron. The reading of the rate of power consumed was then noted to enable estimation of the cost of ironing. In the second comparison, charcoal pressing iron was being used. The cost of the charcoal used to iron at a given time was again noted to know the cost of ironing.

Economic benefit of using sad iron

Table 4.8: Different Iron Types and their Consumption

Type of iron	Ironing time (hr)	Consumption	Cost (₦)
Electric Iron	1	1 Kw	24.30

Charcoal Iron	1	2 kg	150
Sad Iron	1	0	0

Table 4.8 above shows the consumption of different pressing irons after being used for one hour to iron clothes. The table shows that using electric iron for an hour cost ₦24:30 aside the initial purchase of the iron. Similarly, using the charcoal iron for the same period of time cost ₦ 150: 00, also without the initial cost price of the local charcoal iron. On the contrary, without the initial cost price of the sad iron and its solar concentrator and accessories, the sad iron was used to iron for an hour at no cost.

CONCLUSION AND RECOMMENDATIONS

Conclusion

A dish solar heater (PDSH) was installed and used. A sad iron of mass 2.36 kg was designed, casted and test run for a period of five month in Nasarawa, Nasarawa state Nigeria in 2017. Temperature readings of the heated sad iron were also taken for a period of eight months. The readings for the first three months (January to march, 2017) were taken from 8:00 am to 5:00 pm. Readings from theses first three months established that the maximum sad iron temperature readings were obtained at about 2:00 pm. Hence, sad iron temperature readings from April to august were taken from 8:00 am to 2:00 pm daily.

Readings of time taken to use sad iron to iron clothes were also taken from April to May on daily basis as from 2:00 pm. From these ironing period and ironing temperature is was established that the higher the temperature of the sad iron, the more the ironing period but depending on the fabric material being ironed.

This work therefore gave another application of utilizing the abundance solar (renewable) energy in domestic use as a means to reduce the power consumption on the Nigerian national grid.

Recommendations

The utilization of off-national grid sad iron to press clothes was achieved to a large extent. However, further work can still be done on this research area to increase the rate of heating the sad iron and to a much higher temperature, as this will further improve on the ironing time. With the availability of good solar radiation in Nasarawa a more sophisticated iron can be produced for industrial and commercial use.

All efforts to get a millivolt meter to be attached to the sad iron as a temperature reading device proved abortive as this is not available in our local market. Hence, further research can be undertaken to fabricate a local temperature reading instrument attached to this iron.

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