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Performance of Parabolic Concentrated Solar Cooker used for Cooking Oil in Bauchi-Nigeria

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Abstract – *Rural communities in sub Saharan Africa spent considerable time and energy in their quest for obtaining cooking requirements. The utilization of solar energy for cooking is not a widespread practice despite of the fact that African countries are having abundant solar resources. Solar cooker uses the freely, environmentally friendly, healthy and renewable solar energy resources as its energy source, thus indicating its economical and sustainability advantages. The paper demonstrated the possibility of using solar energy as an alternative to the traditional system of cooking local food stuffs in rural communities of North-East Nigeria. The cooker was designed and fitted with a black pot and an automatic tracking mechanisms which track the sun at 10 per hour of the sun movement for use in tropical dry climates. Parboiled rice of 1kg each was cooked completely in 75 minutes at an average solar beam radiation of 623W/m2 after attaining maximum temperature of 368K under clear weather condition. Whereas 1kg of beans and 1.1kg of yam were cooked in 90 minutes at an average solar beam radiation of 536.5W/m2 and 430.1 W/m2 respectively. The highest temperature reached for this test was 368K. The results indicated that parabolic solar cooker can comfortably cooked these varieties of Nigerian local dishes within the range of 75 minutes to 90 minutes under the clear weather condition of Bauchi, north–east of Nigeria.*

Keywords: Solar cooker; food stuffs; parabolic concentrator; solar radiation, Nigeria.

1.0 INTRODUCTION

The prevalent energy crises across the globe necessitate the desired to exploit new and renewable energy sources which are readily available at almost negligible cost among which included the solar energy with an infinite potential [1]. The sun is inexhaustible and secure source of energy that delivers sunshine free to all people. Its greatest potentials lies in providing low temperature heat for space and water heating, but it can equally be converted into high temperature using focusing solar collectors [2-4]. Cooking with solar energy is not common in Nigeria despite of the fact that it lies within the high sunshine belt of the world. The annual available total horizontal radiation Nigeria varies from 5000 to 9400MJ/m2 giving a range of monthly radiation of 416.7 – 783.3 MJ/M2 [5]. For instance, there is hitherto no serious work done in Nigeria to develop a solar cooker that can serve as excellent alternative to fossil fuel-based cookers. As such rural communities in tropical region of north-east Nigeria spent considerable time and energy in their quest for obtaining cooking requirements[6] . It is therefore necessary to look for an alternative source of energy to partially meet the cooking needs of the people living in such areas blessed with sunshine. The solar cooking technology is the simplest, safest, clean, environment friendly, and most convenient way to cook food without consuming fuels or heating up the kitchen [7-11]. The use of solar energy to cook food presents a viable alternative to the use of biomass and fossil fuels traditionally used in developing countries for the purpose of preparing food. While certainly, solar cookers cannot entirely halt the use of combustible fuels for food preparation, it has been shown that properly applied solar cooking can be used as an effective mitigation tool with regards to global climate change and economic debasement of the world's poorest region [12-14]. However, there are some developments elsewhere, in India for instance, a concentrator type solar cooker consisting of a medium size parabolic disc had been developed [8, 15-17]. The development of a parabolic concentrating solar cooker that makes use of the high solar radiations in the tropical region for heating purposes is a most welcome development, especially among the rural dwellers[18]. Several factors including availability of traditional cooking fuels, climate, food preferences, access to materials and technical capabilities affect people's perception of solar cooking. Solar cooker is an innovative way of utilizing the solar energy to cook food. This paper focuses on performance characteristics of a parabolic solar cooker which can be used for domestic solar cooking. It is in the light of this, that this paper evaluated the performance of solar cooker using parabolic concentrator type for cooking local food stuffs in rural communities of Bauchi North-East Nigeria.

2.0 METHODOLOGY

Performance of parabolic concentrating solar cookers is quite sensitive to operational conditions, and therefore, performance evaluation of the parabolic concentrator solar cooker was carried out, in which the cooker was tested for its thermal performance and cooking abilities. Tests were done to evaluate the time taken to cook a certain quantity of food items like rice, yam and beans for which almost an equal quantity of these items were cooked individually on the solar cooker using equal quantity of water. During the tests, the ambient temperature, direct solar radiation and time taken to cook the food were recorded. The cooker was found capable of cooking all the food items and has relatively demonstrated that it can be efficiently used for domestic purposes. The tracking arrangement, operation, loading and unloading were also found to be convenient to use. However, the exposed pot sustained considerable heat loss in the windy season resulting in longer cooking hours.

2.1 Cooking Test of the Parabolic Solar Cooker

After the construction of the solar cooker, testing were carried out in the months of June and July, 2013 to evaluate its performance under different prevailing weather conditions. The cooker was placed under the sun and positioned in the east–west orientation at a slope of 10.3^0 being the angle latitude for Bauchi town where the cooker was tested.

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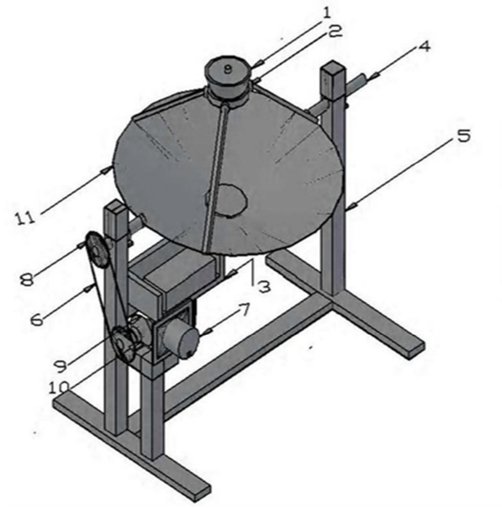
2.2 Testing procedure of the Parabolic Solar Cooker

Testing were done to evaluate its performance under different prevailing weather conditions. The cooker was placed under the sun and positioned in the east–west orientation at a slope of 10.3^0 being the latitude angle where the cooker was tested. Since the cooker is fitted with automatic tracking mechanism, the tracking was done automatically at 1^0 per hour movement of the sun by an electrically operated single axis tracker. The schematic block diagram of the cooker arrangements and its different projection views are shown in figure 1 and 2 respectively. During testing, temperatures at different points of the cooker were recorded; absorber temperature (T_a), pot cover temperature (T_c), cooking fluid temperature (T_f) and ambient temperature (T_{am}) were recorded using K-type thermocouples and Kane-May KM 330 Digital temperature data logger. The thermocouples were the grounded junction type, their sizes were such that they caused less obstruction to heat and their accuracy was ± 0.1^{o}C when employed with the digital temperature data logger. Instantaneous global components of solar radiation were measured using two pyranometers: the CM6B model manufactured by KIPP & ZONEN DELFT Holland, which measured the global solar radiation and the CM11/121 type fitted with shadow ring which measured the instantaneous diffused component of solar radiation, both pyranometers were calibrated as $9.63 \times 10^{-6} V/Wm^{-2}$.



S/N	PARTS
1.	COOKING POT
2.	POT HOLDER
3.	
4.	CONTROL CIRCUITRY BOX
5.	SHAFT
6.	FRAME
7.	CHAIN
8.	STEPPER MOTOR
9.	SPOROCKET
10.	BEVEL GEAR
11.	BEARING
12.	DISH

Figure1: Block diagram of parabolic concentrating solar cooker

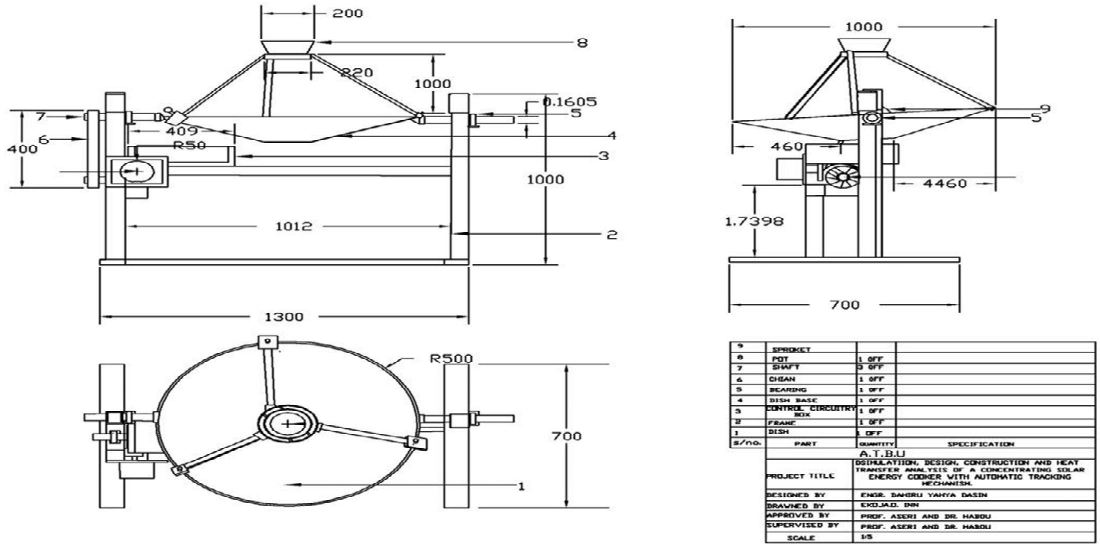


Figure 2: Different projection views of the concentrating parabolic solar cooker

Furthermore, wind speed was measured to observe its effect on the performance of the cooker using cup counter anemometer, its accuracy was about ± 1%. The cooking tests of rice, beans and yam were carried out three times at different prevailing weather conditions as shown in tables 1 to 9 respectively.

Table 1: Experimental Temperature Distribution at Various Point for cooking Test of Rice

T_D Day	T_a K	T_{as} K	T_c K	T_f K	T_g K	T_{am} K	G_R W/m^2	D_R W/m^2	B_R W/m^2	W_S m/s
10:00	300	300	302	300	301	302	415.4	207.7	208	0.70
10:15	329	319	318	325	323	303	623.1	207.7	415	0.70
10:30	361	316	325	351	338	307	726.9	207.7	519	0.70
10:45	363	316	325	353	335	305	726.9	207.7	519	0.80
11:00	362	315	320	360	337	305	726.9	207.7	519	0.80
11:15	367	325	333	362	340	305	830.7	207.7	623	0.80
11:30	366	328	336	366	344	305	830.7	207.7	623	0.80
11:45	367	332	337	368	345	306	830.7	207.7	623	0.80

Weather Condition: Clear; Setting Time: 10;00 a.m.; Average Wind Speed: 0.8 m/s, Average Insolation: 623 w/m^2; Date: 12/06/2013; Mass of Fluid: 800g water + 200g Rice (white); T_D =Time of the day;T_a=Absorber Temperature base; Tas=Absorber Temp side; Tc=Pot cover temperature; Tf=cooking fluid Temperature; Tg= Air gab Temperature; Tam= Ambient Temperature ; G_R =Global Radiation; D_R=Diffuse Radiation;B_R=Beam Radiation ;Ws=Wind Speed.

Table 2: Experimental Temperature Distribution at Various Point for cooking Test of Rice

T_D	T_a K	T_{as} K	T_c K	T_f K	T_g K	T_{am} K	G_R W/m^2	D_R W/m^2	B_R W/m^2	W_S m/s
12:00	304	304	305	300	304	305	830.7	207.7	623	0.80
12:15	344	315	313	326	326	310	830.7	207.7	623	0.70

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12:30	386	348	325	346	344	308	830.7	207.7	623	0.70
12:45	383	362	339	354	359	308	830.7	207.7	623	0.80
1:00	373	363	348	362	367	306	830.7	207.7	623	0.80
1:15	374	365	339	368	367	307	830.7	207.7	623	0.80

Weather Condition: Clear; Setting Time: 12;00 p.m.; Average Wind Speed: 0.8 m/s, Average Insolation: 623 w/m^2; Date: 13/06/2013; Mass of Fluid: 800g water + 200g Rice (white); T_D =Time of the day;T_a=Absorber Temperature base; Tas=Absorber Temp side; Tc=Pot cover temperature; Tf=cooking fluid Temperature; Tg= Air gab Temperature; Tam= Ambient Temperature ; G_R =Global Radiation; D_R=Diffuse Radiation;B_R=Beam Radiation ;Ws=Wind Speed

Table 3: Experimental Temperature Distribution at Various Point for cooking Test of Rice

T_D	T_a K	T_{as} K	T_c K	T_f K	T_g K	T_{am} K	G_R W/m^2	D_R W/m^2	B_R W/m^2	W_S m/s
11:00	303	303	304	302	303	304	830.7	207.7	623	0.90
11:15	346	338	313	339	336	304	830.7	207.7	623	0.90
11:30	364	342	325	357	351	304	830.7	207.7	623	1.20
11:45	370	354	336	360	359	306	830.7	207.7	623	0.40
12:00	383	366	345	367	362	306	830.7	207.7	623	0.40
12:15	377	363	346	367	365	306	830.7	207.7	623	0.40

Weather Condition: Clear; Setting Time: 11;00 a.m.; Average Wind Speed: 0.8 m/s, Average Insolation: 623 w/m^2; Date: 14/06/2013; Mass of Fluid: 800g water + 200g Rice (white); T_D =Time of the day;T_a=Absorber Temperature base; Tas=Absorber Temp side; Tc=Pot cover temperature; Tf=cooking fluid Temperature; Tg= Air gab Temperature; Tam= Ambient Temperature ; G_R =Global Radiation; D_R=Diffuse Radiation;B_R=Beam Radiation ;Ws=Wind Speed.

Table 4: Experimental Temperature Distribution at Various Point for cooking Test of Beans

T_D Day	T_a (K)$_{base}$	T_{as} (K)$_{sides}$	T_c K	T_f K	T_g K	T_{am} K	G_R W/m^2	D_R W/m^2	B_R W/m^2	W_S m/s
10:15	301	301	302	295	302	302	623.1	207.7	415	0.60
10:30	345	312	321	332	328	306	726.9	207.7	519	0.60
10:45	367	326	330	346	342	305	726.9	207.7	519	0.50
11:00	363	329	332	356	352	304	726.9	207.7	519	0.50
11:15	376	343	347	363	361	304	830.7	207.7	623	0.50
11:30	371	352	338	368	367	306	830.7	207.7	623	0.30

Weather Condition: Clear; Setting Time: 10:15 a.m.; Average Wind Speed: 0.5 m/s, Average Insolation: 536 w/m^2; Date: 15/06/2013; Mass of Fluid: 800g water + 200g Beans; T_D =Time of the day;T_a=Absorber Temperature base; Tas=Absorber Temp side; Tc=Pot cover temperature; Tf=cooking fluid Temperature; Tg= Air gab Temperature; Tam= Ambient Temperature ; G_R =Global Radiation; D_R=Diffuse Radiation;B_R=Beam Radiation ;Ws=Wind Speed

Table 5: Experimental Temperature Distribution at Various Point for cooking Test of Beans

T_D Day	T_a (K)$_{base}$	T_{as} (K)$_{sides}$	T_c K	T_f K	T_g K	T_{am} K	G_R W/m^2	D_R W/m^2	B_R W/m^2	W_S m/s
12:00	302	302	309	305	309	306	830.7	207.7	623	0.70

12:15	356	324	336	334	331	307	830.7	207.7	623	0.80
12:30	361	337	338	347	344	307	830.7	207.7	623	0.70
12:45	353	325	341	356	353	305	830.7	207.7	623	0.70
1:00	351	322	335	362	356	306	415.4	207.7	208	0.60
1:15	362	330	339	363	361	306	726.9	207.7	519	0.70
1:30	374	343	341	367	364	306	830.7	207.7	623	0.70

Weather Condition: Clear; Setting Time: 12:00 pm a.m.; Average Wind Speed: 0.7 m/s, Average Insolation: 548.9 w/m^2; Date: 16/06/2013; Mass of Fluid: 800g water + 200g Beans; T_D =Time of the day;T_a=Absorber Temperature base; Tas=Absorber Temp side; Tc=Pot cover temperature; Tf=cooking fluid Temperature; Tg= Air gab Temperature; Tam= Ambient Temperature ; G_R =Global Radiation; D_R=Diffuse Radiation;B_R=Beam Radiation ;Ws=Wind Speed.

Table 6: Experimental Temperature Distribution at Various Point for cooking Test of Beans

T_D Day	T_a K	T_{as} K	T_c K	T_f K	T_g K	T_{am} K	G_R W/m^2	D_R W/m^2	B_R W/m^2	W_S m/s
10:00	305	300	302	300	301	302	415.4	207.7	208	0.70
10:15	323	316	310	325	322	303	624.1	207.7	415	0.70
10:30	351	316	323	350	336	304	726.9	207.7	517	0.70
10:45	363	316	325	353	335	305	727.9	207.7	517	0.80
11:00	362	315	320	359	337	305	726.9	207.7	517	0.80
11:15	367	324	331	361	340	305	830.7	207.7	623	0.80
11:30	366	328	335	364	343	306	830.7	207.7	623	0.80
11:45	367	333	336	367	346	306	830.7	207.7	623	0.80

Weather Condition: Clear; Setting Time: 12:00 pm a.m.; Average Wind Speed: 0.7 m/s, Average Insolation: 548.9 w/m^2; Date: 16/06/2013; Mass of Fluid: 800g water + 200g Beans; T_D =Time of the day;T_a=Absorber Temperature base; Tas=Absorber Temp side; Tc=Pot cover temperature; Tf=cooking fluid Temperature; Tg= Air gab Temperature; Tam= Ambient Temperature ; G_R =Global Radiation; D_R=Diffuse Radiation;B_R=Beam Radiation ;Ws=Wind Speed.

Table 7: Experimental Temperature Distribution at Various Point for cooking Test of Yam

T_D Day	T_a $(K)_{base}$	T_{as} $(K)_{sides}$	T_c K	T_f K	T_g K	T_{am} K	G_R W/m^2	D_R W/m^2	B_R W/m^2	W_S m/s
9:30	301	301	302	300	302	302	519.2	207.7	312	1.00
9:45	335	311	313	319	314	302	519.2	207.7	312	1.20
10:00	352	311	324	332	326	303	623.1	207.7	415	1.20
10:15	357	319	327	343	336	303	623.1	207.7	415	1.30
10:30	375	342	328	356	350	304	726.9	207.7	519	0.90
10:45	367	335	325	359	348	304	726.9	207.7	519	0.90
11:00	374	350	341	364	361	304	726.9	207.7	519	1.00

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Weather Condition: Clearwith little high wind speed; Setting Time: 12:00 pm a.m.; Average Wind Speed: 1.1 m/s, Average Insolation: 430.1 w/m^2; Date: 19/06/2013; Mass of Fluid:300 water + 800g Yams; T_D =Time of the day;T_a=Absorber Temperature base; Tas=Absorber Temp side; Tc=Pot cover temperature; Tf=cooking fluid Temperature; Tg= Air gab Temperature; Tam= Ambient Temperature ; G_R =Global Radiation; D_R=Diffuse Radiation;B_R=Beam Radiation ;Ws=Wind Speed.

Table 8: Experimental Temperature Distribution at Various Point for cooking Test of Yam

T_D Day	T_a (K)$_{base}$	T_{as} (K)$_{sides}$	T_c K	T_f K	T_g K	T_{am} K	G_R W/m^2	D_R W/m^2	B_R W/m^2	W_S m/s
11:30	303	303	306	296	305	306	830.7	207.7	623	1.00
11:45	338	314	324	314	313	306	830.7	207.7	623	0.90
12:00	363	338	328	333	331	305	830.7	207.7	623	0.90
12:15	368	340	330	343	340	306	726.9	207.7	519	1.10
12:30	374	348	333	351	351	307	830.7	207.7	623	1.00
12:45	372	346	332	363	355	307	623.1	207.7	415	1.00

Weather Condition: Clearwith little high wind speed; Setting Time: 11:30 a.m.; Average Wind Speed: 0.98 m/s, Average Insolation: 571.2 w/m^2; Date: 20/06/2013; Mass of Fluid:300 water + 800g Yams; T_D =Time of the day;T_a=Absorber Temperature base; Tas=Absorber Temp side; Tc=Pot cover temperature; Tf=cooking fluid Temperature; Tg= Air gab Temperature; Tam= Ambient Temperature ; G_R =Global Radiation; D_R=Diffuse Radiation;B_R=Beam Radiation ;Ws=Wind Speed.

Table 9: Experimental Temperature Distribution at Various Point for cooking Test of Yam

T_D Day	T_a (K)$_{base}$	T_{as} (K)$_{sides}$	T_c K	T_f K	T_g K	T_{am} K	G_R W/m^2	D_R W/m^2	B_R W/m^2	W_S m/s
1:15	303	303	306	297	303	307	830.7	207.7	623	0.80
1:30	340	316	326	312	310	307	830.7	207.7	623	0.80
1:45	364	337	330	334	331	306	830.7	207.7	623	0.70
2:00	375	355	333	345	342	306	830.7	207.7	623	0.60
2:15	373	351	331	352	348	306	726.9	207.7	519	0.60
2:30	372	348	330	360	355	305	726.9	207.7	519	0.60
2:45	374	353	334	363	362	305	726.9	207.7	519	0.60

Weather Condition: Clear; Setting Time1:15 p.m.; Average Wind Speed: 0.67 m/s, Average Insolation: 578.6 w/m^2; Date: 21/06/2013; Mass of Fluid:300 water + 800g Yams; T_D =Time of the day;T_a=Absorber Temperature

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base; Tas=Absorber Temp side; Tc=Pot cover temperature; Tf=cooking fluid Temperature; Tg= Air gab Temperature; Tam= Ambient Temperature ; G_R =Global Radiation; D_R=Diffuse Radiation;B_R=Beam Radiation ;Ws=Wind Speed.

3.0 RESULT AND DISCUSSION

Figures 1, 2 and 3 shows results of temperature plots against various timing from 10: 00am up to 1: 12pm for cooking rice under weather condition of 623Wm-2 average beam radiation and 0.8 ms-1 average wind speed respectively. In all the results, it can be clearly seen that the absorber temperature reaches its peak when the sun is vertically overhead and have the highest temperature values then followed by cooking fluid temperature which indicates the efficiency of the cooking process. From the graphical results it can be vividly seen that the highest cooking fluid temperature reaches up to 368K (950C) which is hot enough to cook rice though the time taken to accomplished the job might be a little bit longer when compared with the conventional cooking process of rice, it can still be acceptable taking into consideration its economy and environmental friendliness. The cooking test results of the rice are shown in Tables 1, 2 and 3 respectively.

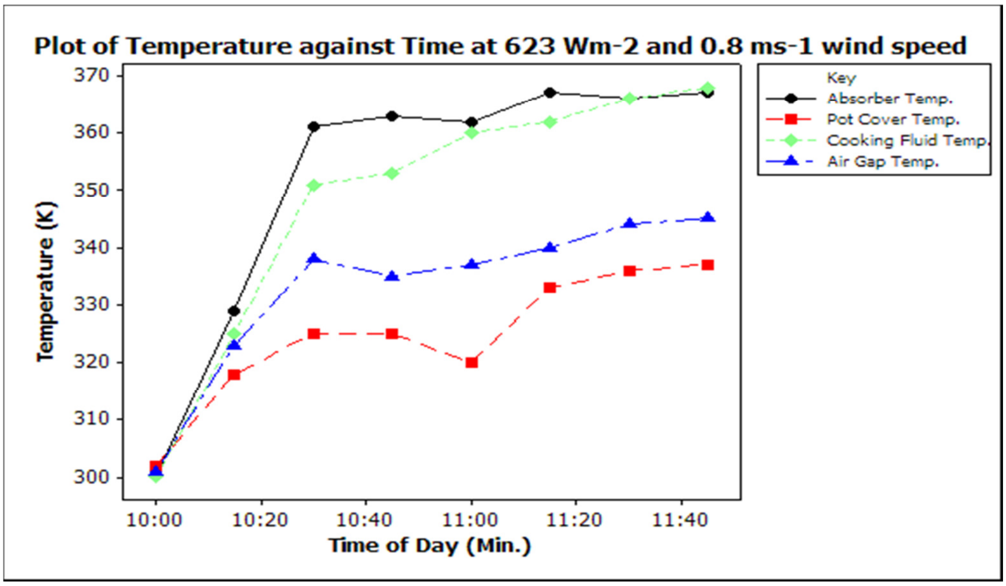

Figure 1: Plot of Temperature against time for cooking 1kg of Rice at 623W/m^2 average beam radiation and average wind speed of 0.8m/s.

Figures 4, 5 and 6 shows results of temperature plots against various timing from 10: 12am up to 1: 40pm for cooking beans under weather condition of 623Wm-2 average beam radiation and 0.8 ms-1 average wind speed respectively. In all the results, it can be clearly seen that the absorber temperature reaches its peak when the sun is nearly vertically overhead and have the highest temperature values then followed by cooking fluid temperature which indicates the efficiency of the cooking process. Furthermore, from the graphical results it can be vividly seen that the highest cooking fluid temperature reaches up to 372K (990C) which is hot enough to cook beans though the time taken to accomplished the job might be a little bit longer when compared with the conventional cooking process of beans, it can still be

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acceptable taking into consideration its economy and environmental friendliness. The cooking test results of the beans are shown in Tables 4, 5 and 6 respectively.

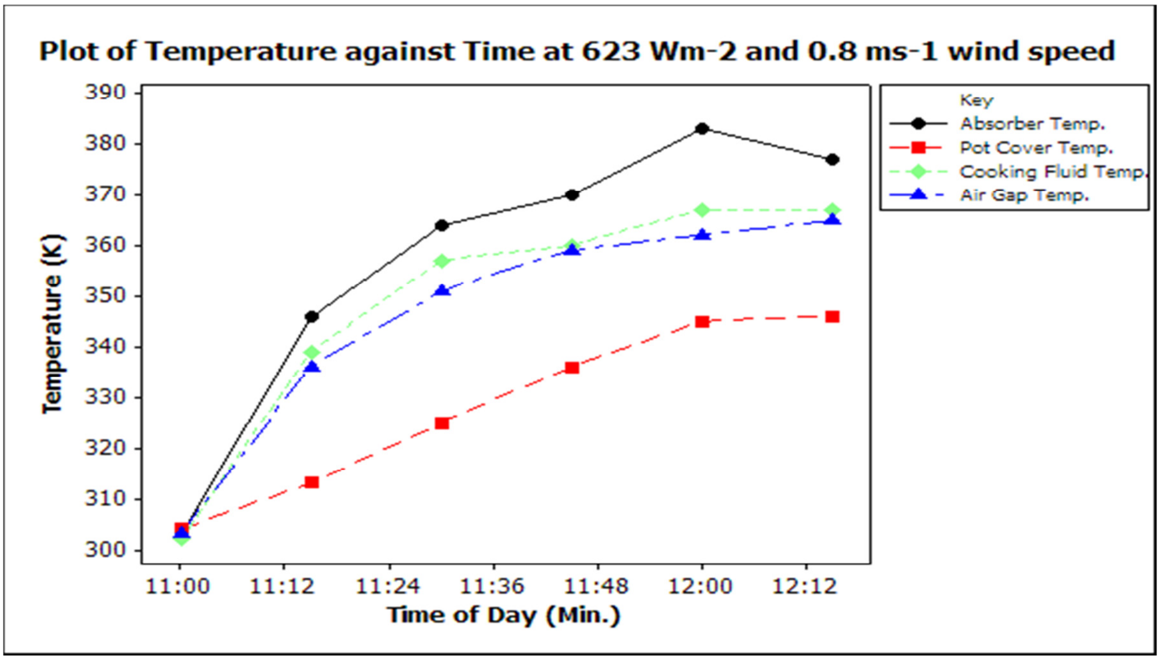

Figure 2: Plot of Temperature against time for cooking 1 kg of rice

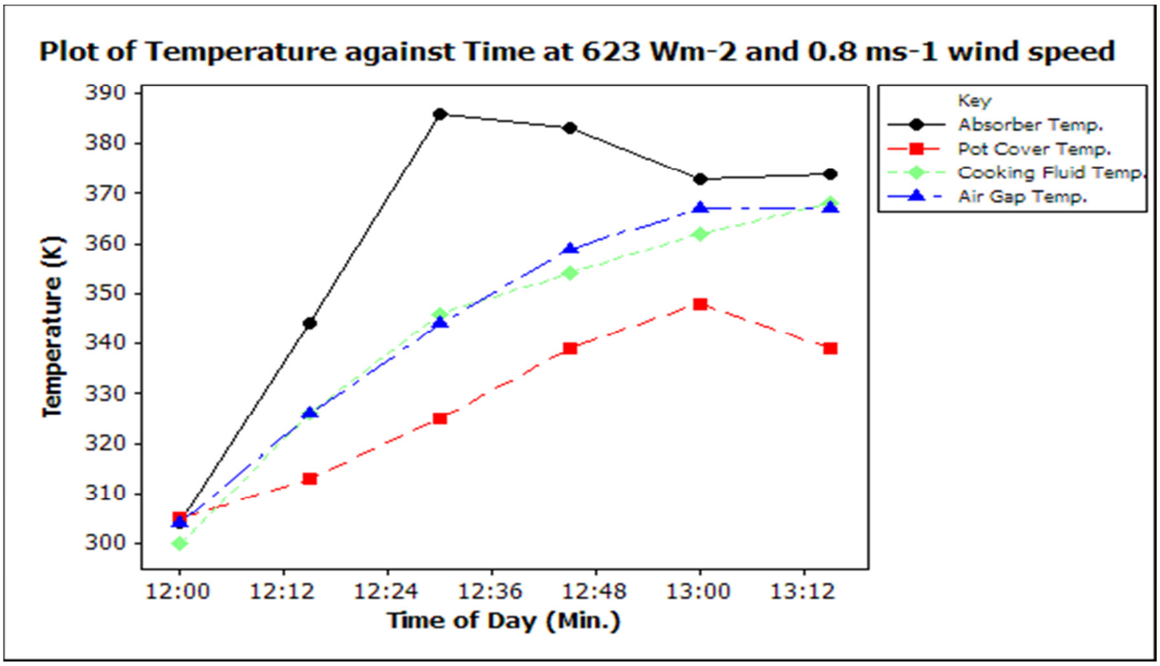

Figure 3: Plot of Temperature against time for cooking 1 kg of rice

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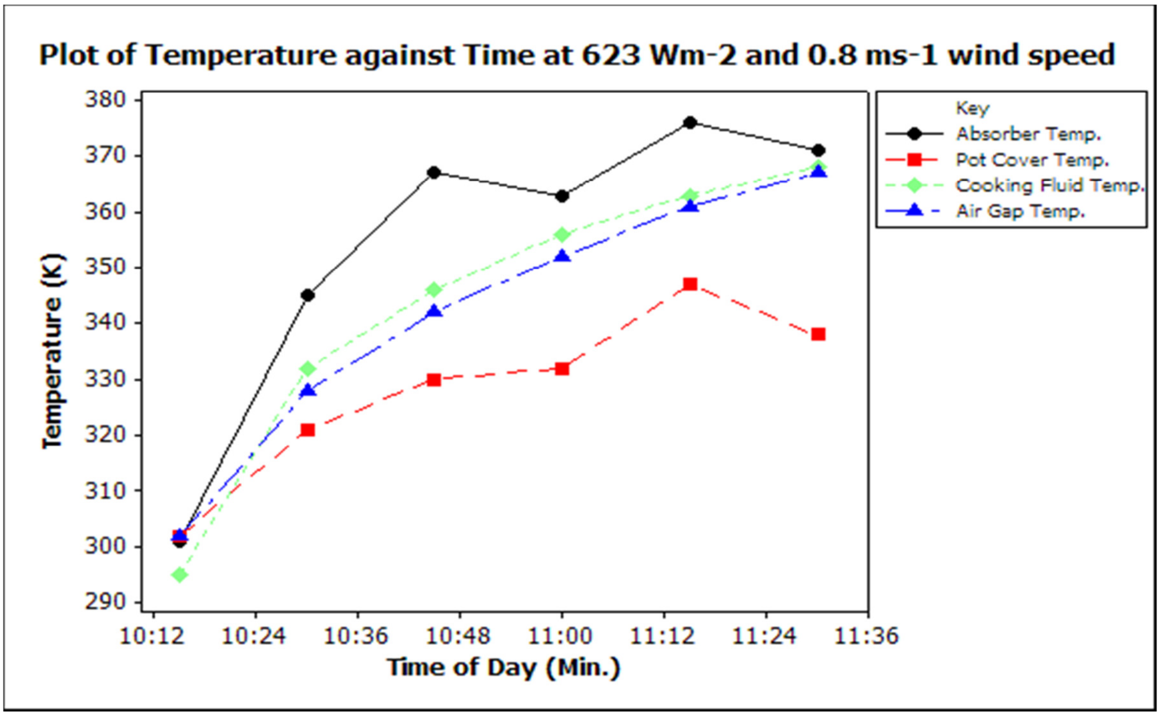

Figure 4: Plot of Temperature against time for cooking 1 kg of beans

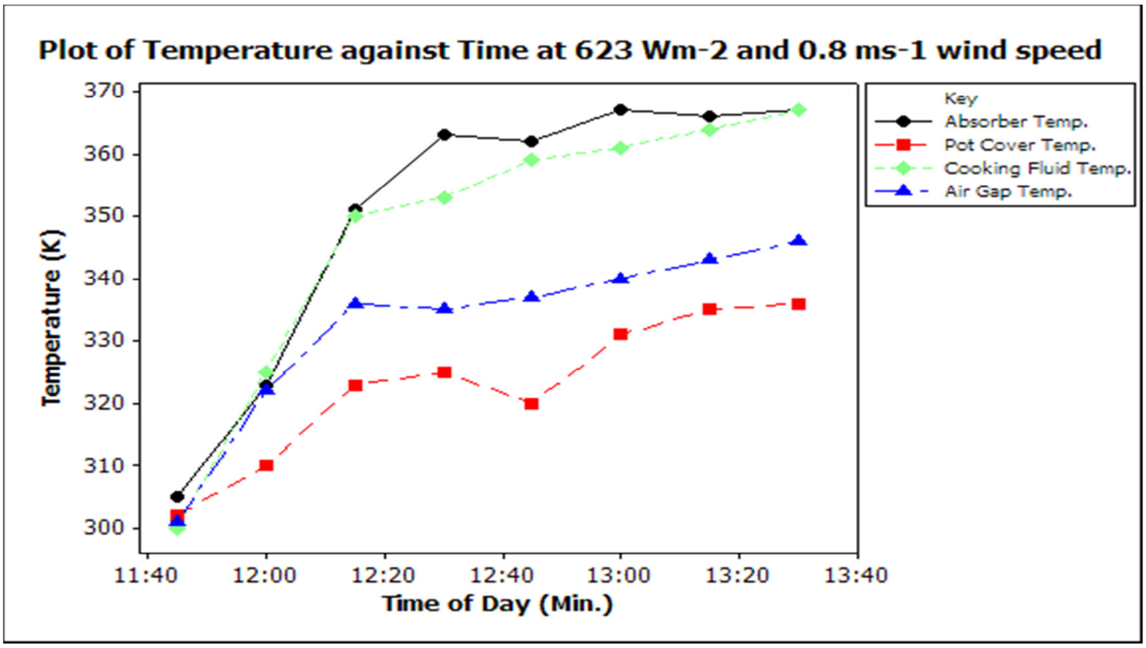

Figure 5: Plot of Temperature against time for cooking 1 kg of beans

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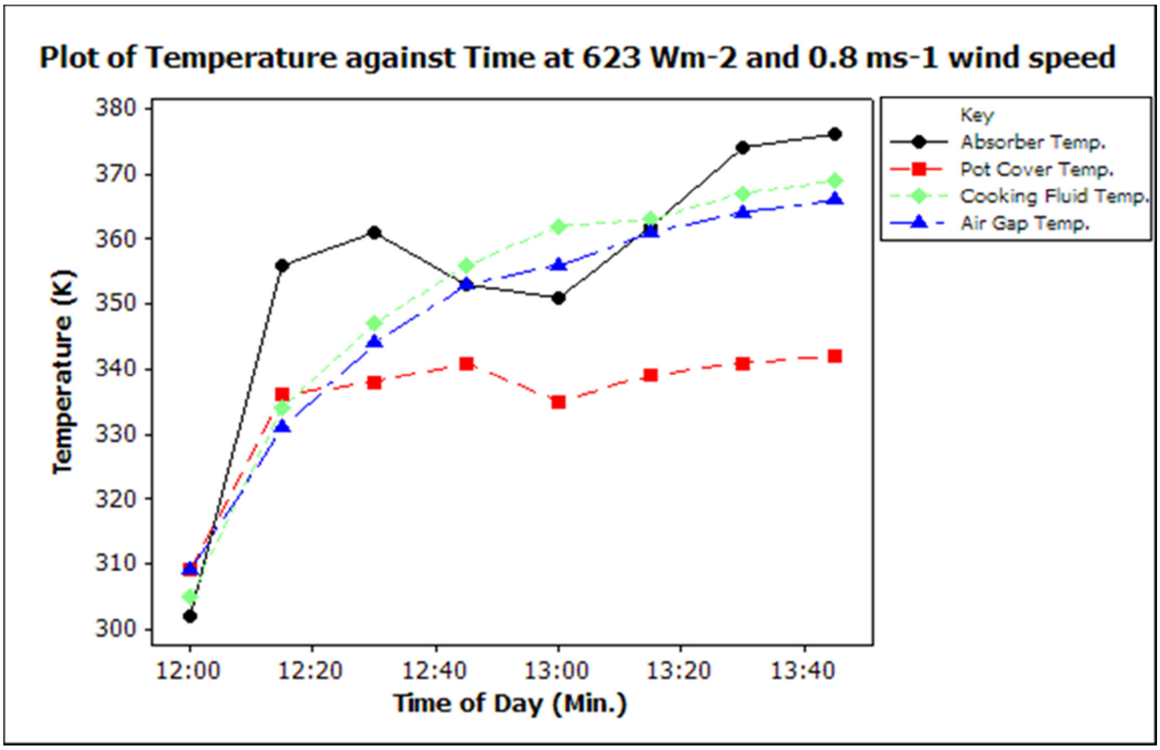

Figure 6: Plot of Temperature against time for cooking 1 kg of beans

Figures 7, 8 and 9 shows results of temperature plots against various timing from 9: 30am up to 2: 45pm for cooking yam under weather condition of 623Wm^{-2} average beam radiation and 0.8 ms^{-1} average wind speed respectively. In all the results, it can be clearly seen that the absorber temperature reaches its peak when the sun is slightly after vertically overhead and have the highest temperature values then followed by cooking fluid temperature which indicates the efficiency of the cooking process. Finally, from the graphical results it can be vividly seen that the highest cooking fluid temperature reaches up to 362K (89^{0}C) which is hot enough to cook yam though the time taken to accomplished the job might be a little bit longer when compared with the conventional cooking process of yam, it can still be acceptable taking into consideration its economy and environmental friendliness. The cooking test results of the yam are shown in Tables 7, 8 and 9 respectively.

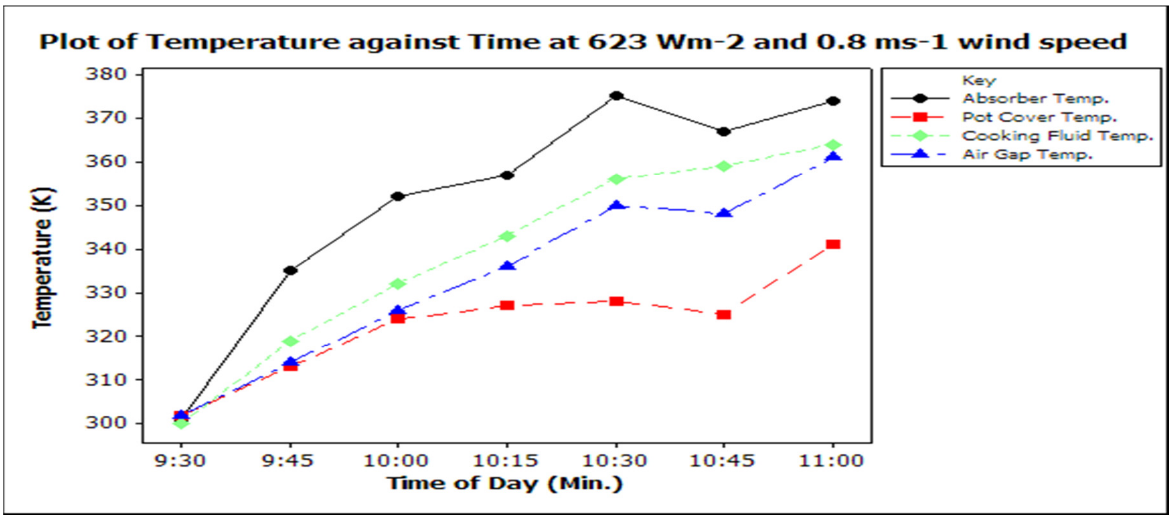

Figure 7: Plot of Temperature against time for cooking 1.1 kg of yam

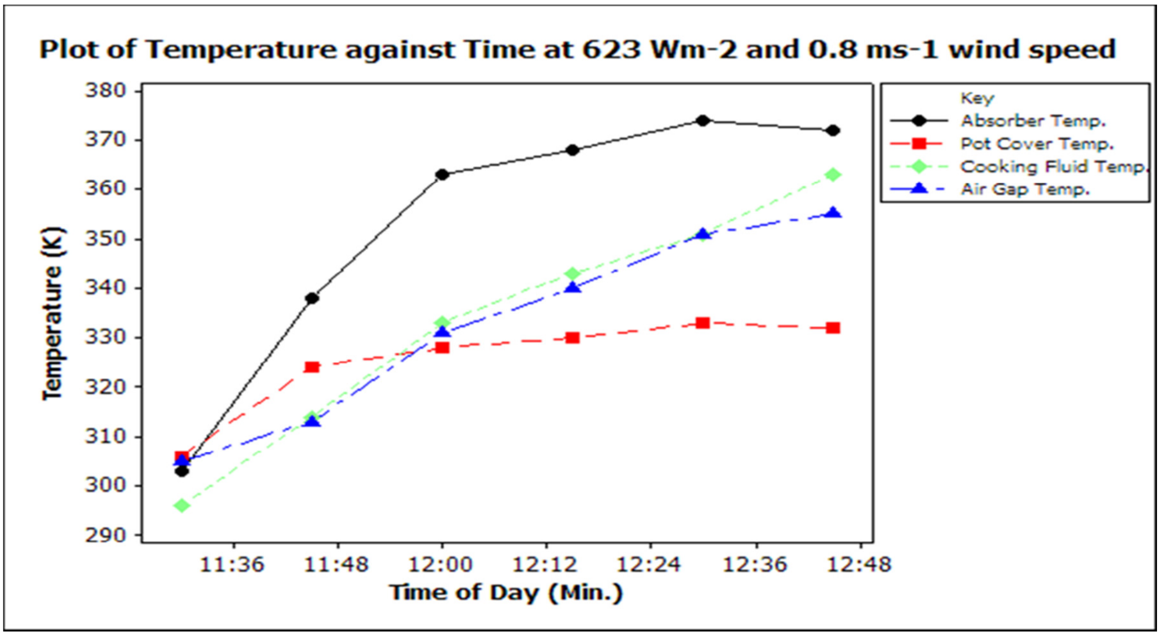

Figure 8: Plot of Temperature against time for cooking 1.1 kg of yam

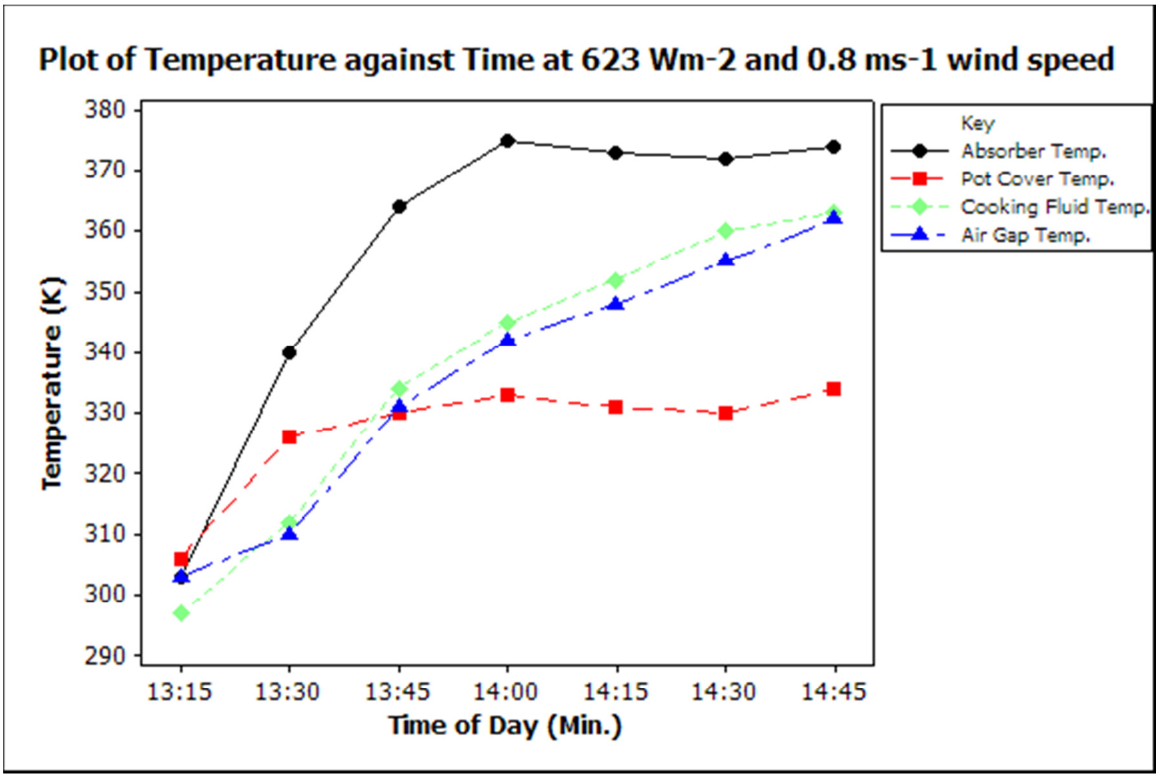

Figure 9: Plot of Temperature against time for cooking 1.1 kg of yam

4.0 CONCLUSION

The performance evaluation carried out indicates that the parabolic solar cooker can adequately be used for cooking in tropical dry climates such as that of Bauchi Nigeria. All the food stuffs were cooked effectively using the present cooker even though the time taken was a little bit longer when compared with conventional kerosene, gas, fire wood and electric cookers. This is attributed to natural phenomena of cloud interception and rain falls, since the testing was done in the months of June and

July, a period characterized to be of hazy weather and heavy down fall in the area where the readings were taken. It is believed that, the cooker will perform better during sunny days, it is expected that shorter boiling time and consequently higher efficiency would be achieved during dry season under clear weather condition.

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