

DESIGN AND CONSTRUCTION OF CABINET SOLAR DRYERS

Abstract

Two domestic solar dryers were designed and tested in Abraka, Delta State of Nigeria. One has a mirror reflector to concentrate sun – light energy into the dryer while other has no reflector. The dryer ovens were subjected to a number of experimental tests by drying/cooking six different food items in them. The analysis of the results obtained, showed that the temperature and the rate of drying in the oven with reflector were higher than the one without reflector. The temperature and the rate of drying were higher in both ovens compared to the open – air drying. The total power obtained using the oven with reflector was 350.00W, while the oven without reflector gave 330.56W and the open air – drying recorded 233.15W. These could act as an alternative dryer to the conventional open air-drying and cooking for rural farmers in Nigeria and other tropical countries with similar circumstances.

Keywords: oven, reflector, solar energy, food items, ambient temperature

1.0 Introduction

In most developing countries in the tropics such as Nigeria, over 70% of the population lives in rural areas. These people are mainly farmers who preserve their farm products by drying. This drying is a process whereby the water content of a material is reduced to a level where it could be safely stored for future use without the need for refrigeration [1]. The conventional means of drying in these areas has been the use of firewood and the open – air sun drying [2]. Sun drying is only possible in an area where the sun allows food to be dried immediately after harvest [3]. Many cereal crops, vegetables, fruits, prawn and fishes are dried by spreading them sparsely on a prepared open place to receive direct sun light. The advantages of open – air sun drying are low production and operating cost. Moreover, little expertise is required for its daily running. The disadvantages of this method are contamination, theft and massive loss to birds, insects, rodents, domestic animals. They could sometimes be blown away by wind beyond recovery [4, 5]. Slow and intermittent drying has no protection from rain or dews that falls on the product and encourages mould growth. Moreover, the quality (colour and vitamin content) of the products may be diminished due to over – drying or under – drying [6]. Sun – drying depends on uncontrollable factors and hence, the production of uniform standard products is not guaranteed [7].

This has necessitated the invention of a solar cabinet dryer to replace the conventional open – air sun drying. Solar cabinet dryer holds a very promising future for the developing countries

economically since it burns no fuel and the materials for its construction are quite cheap and readily available. It causes no air or water pollutions. It gives a faster drying rate by raising the temperature to about 10°C – 40°C above the ambient temperature. The faster drying reduces the risk of spoilage and improves the quality of the product. Solar cabinet dryer prevents the food from dust, insects, rodent and other animals because it is enclosed in a chamber. Moreover, it can act as an alternative means of cooking in the rural areas where electricity and other sources of energy are skeletal or non-existence. The purpose of this research work is therefore to produce a prototype solar cabinet dryer, which when mass – produced, can conveniently act as an alternative dryer to the conventional open – air drying for rural farmers in Nigeria and other countries with the same circumstances.

2.0 Construction of the dryers

Abraka is a town in the Niger Delta region of Nigeria. It lies on a geographical location coordinates of $5^{\circ} 47' 0'' \text{ N}$ and $6^{\circ} 6' 0'' \text{ E}$ [8]. Moreover, from a daily Metrological forecast, Abraka and its environs has about 28°C on a very cold day and about 40°C on a very hot day. This could conveniently represent a typical example of a tropical temperature. This is very important because the samples considered in this research work are

1. Groundnut,
2. Plantain chips,
3. Fresh pepper,
4. Fresh meat sliced to size,
5. Fresh fish
6. Raw egg

These crops could only be dried or cooked above a specific temperature. The minimum temperature for drying groundnut, fresh pepper and plantain chips is about 45°C to 50°C and for fish and slice meat, the temperature is from 60°C to 75°C . Raw egg needs a steady temperature of about 90°C to 100°C . Hence, this cabinet solar dryer was designed so that its output temperature does not fall below 45°C .

The materials for the construction of the dryers were sourced locally to minimize cost and maximize energy, since the rural farmers are the target. The following materials were used in the construction.

1. Transparent glass (4mm thick)
2. Aluminum foil sheet (0.45mm thick)
3. Nails
4. Hinges
5. Plywood
6. Plane mirrors
7. Wood
8. A very sensitive digital weighing machine

75 9. Three thermometers (mercury in glass)

76 10. A timekeeper

77 11. A knife

78 12. A stool

79 13. A flat wooden plate

80 In the construction of the solar dryers, wood of about 5 mm^2 area was cut to dimension to build
81 the skeletal frame work and then nailed together. This is to make the boxes very rigid. The boxes
82 have length of 80 cm, width 50 cm and a depth of 40 cm. Then the plywood was cut to
83 specification and used to cover five sides of each of the dryers, while the top space was left open
84 for the plane glass. The two length views were $(80 \times 40)\text{ cm}^2$, the two side views were (50×40)
85 cm^2 and the bottom corner was $(80 \times 50)\text{ cm}^2$. The parts, which form the outer covering of the
86 dryers, were nailed together using one – inch nails. The position of the vent were marked with
87 the tape and chiseled out. A wire net was used to cover the vent from inside to prevent the
88 samples from being lost through it. A small plywood board was fitted to the outside so that the
89 vent could be slide open and closed to ventilate the oven and allow moisture to escape from it.

90 After the construction of the framework of the dryers, aluminum sheet of 0.45 mm thick was
91 measured according to the dimension of the dryers with the position of vents cut open with a
92 scissors. Then thin foam was used to line the inside and held with one – inch nail before folding
93 the aluminum sheet inside the boxes. The foam was lined uniformly so that the entire oven could
94 have a uniform heating effect. It will also act as an insulator between each of the wooden boxes
95 and the aluminum sheet. The aluminum sheet was then folded inside each of the boxes and
96 nailed to the wood. At this stage, a hole for the thermometer was drilled by the top side of each
97 of the two dryers with a perforator. The space for the door was measured and wood of equal
98 dimension was used to construct it. Two half – inch hinges were fixed to each of the doors with
99 one – inch nails so that they could be opened and closed at will to load or remove the samples.
100 All possible openings between the door and the respective boxes were sealed up with thin foam
101 and nailed to the wood to reduce heat loss whenever the door is opened or closed.

102 The inside compartments were painted black to increase the rate of absorption of heat. The plane
103 glass was cut to size of about $(50 \times 80)\text{ cm}^2$ in dimension with a diamond blade and then used to
104 cover the open top of the dryers. An evostic gum was used to rub on the surface of the boxes
105 before fixing the glass. This is to hold the glass firmly to it. A one – inch plank was used to line
106 the sides of the glass and nailed to the each of the boxes. The transparent glass cover allows the
107 solar energy to get to the samples and at the same time reduce heat loss by convection,
108 conduction and radiation. The boxes were mounted with four legs of about 80 cm length using
109 wood of 5mm^2 to raise them off the ground.

110 Finally, the plane mirrors were cut to dimension of $(80 \times 25)\text{ cm}^2$ with a diamond blade.

111 Plywood was used to form a frame at the back of the mirror so that it could be mounted on the
112 top of the dryer length – wise (One on each top sides of the box). Four (half– inch) hinges were
113 used to nail the frame with the mirrors to the top side of one of the boxes as shown in figure 1

below. The hinges were held with one – inch nails to ensure that the mirrors could be rotated up to an angle of 120^0 . The rays of the sun are scattered in all directions. The rays perpendicular to the dryer fall directly into the oven, while those moving at an angle are reflected into the oven by the mirror for effective result. These mirrors were adjusted according to the position of the sun so that enough sunrays could be reflected back into the oven.

The dryer with mirror reflector was labeled as oven 1, while the dryer without the mirror reflector was oven 2. Figure 1 below shows the solar dryer with mirror reflector, while figure 2 shows the solar dryer without the mirror reflector.

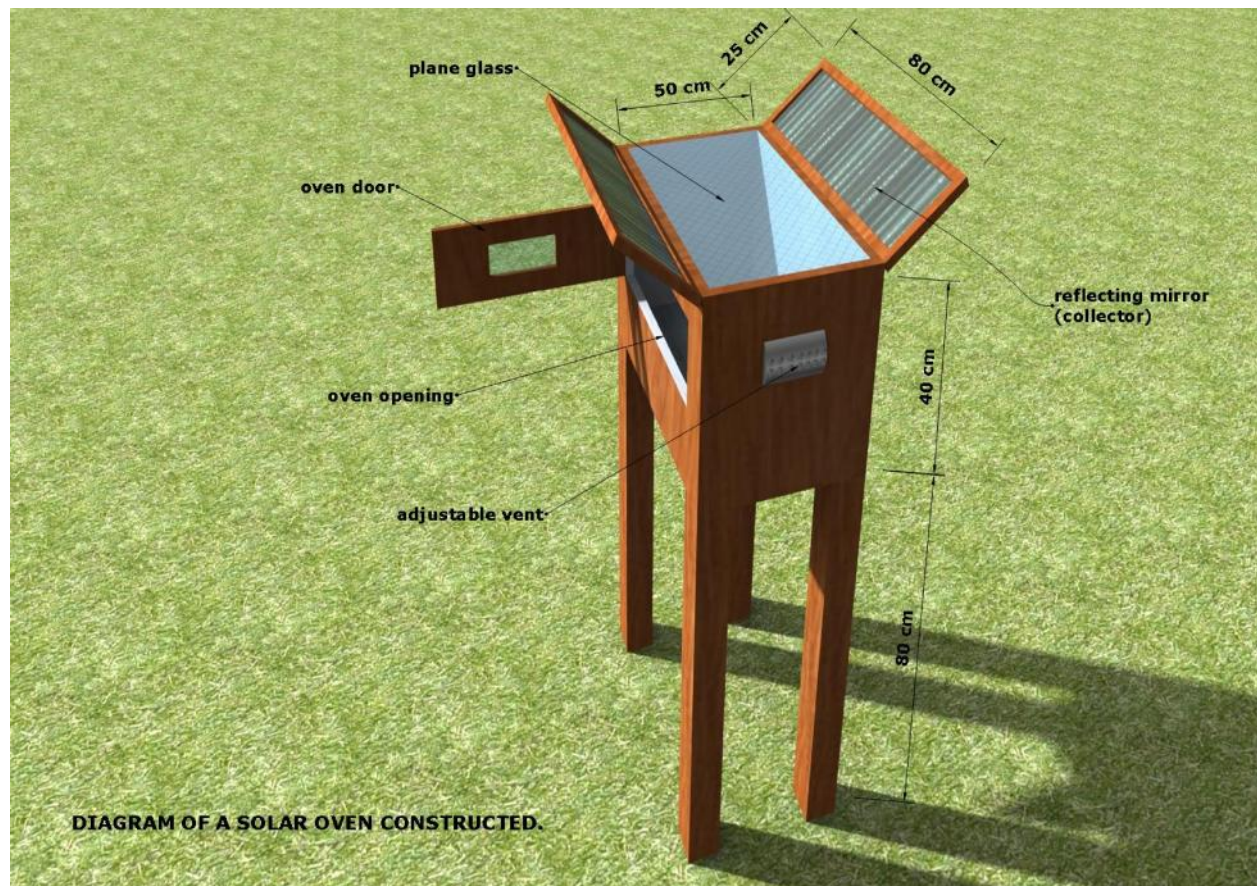


Figure 1: The solar cabinet dryer with mirror reflector

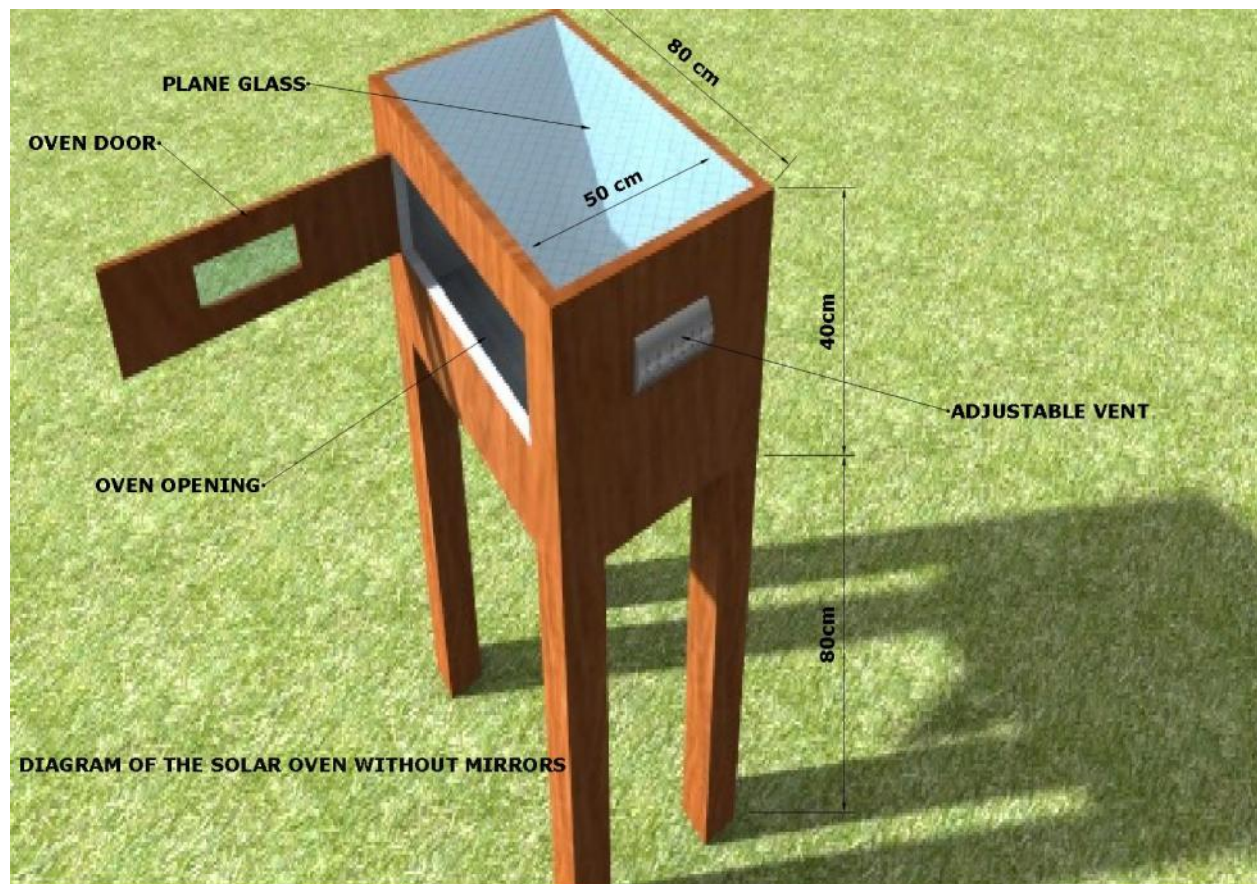


Figure 2: Solar cabinet dryer without the mirror reflector

3.0 Data Collection and Result

At the beginning of each experiment, a thermometer was placed at the top side of each of the two solar dryers and on the specimen for the open air – drying. The food samples to be used were weighed and labeled as follows

Specimen A were loaded into oven 1

Specimen B were loaded into oven 2

Specimen C was kept outside for open air – drying.

These constructed solar dryers were brought out into the open. Oven 1 was positioned facing the sunrise and the reflector mirrors tilted so that enough sun rays could be reflected back into the oven. Oven 2 was equally position in an open place to receive direct sun light. The specimen for the open air – drying was scattered on an aluminum plate (80 x 50) cm² which was painted black and then placed on top of a stool and positioned in an open place. The time, temperature and mass of each sample were recorded before being loaded into the ovens at the commencement of each day's experiment. These readings were taken every one and half – hour. The experiments

were set up by 9.30 am each day and it runs until the temperature goes down about 3.30 pm. On the 1st and 2nd days, groundnut and sliced plantain were loaded together into the ovens. On the 3rd and 4th days, fresh pepper and sliced meat were loaded together into the ovens, while on the 5th and 6th days, only sliced fresh fish was used as sample. Then on the 7th day, raw eggs were cooked in the two solar dryers. The results are shown in the tables below.

The precautions taken in this experiment to ensure maximum output are as follows:

1. The dryers were placed in an open place where nothing could cast shadow on them.
2. The drying pan for loading the samples into the dryers were made of the same material with that of the control experiment for the open air – drying placed outside the dryers. This will ensure that the same environment was created for the three ovens to avoid systematic error.
3. The three ovens were made of aluminum coil painted black so that the power output could be comparatively computed.

Tables 1 and 2 shows the measurements recorded for fresh groundnut on the 1st and 2nd days respectively. While tables 3 and 4 are the measurements recorded for sliced plantain on the 1st and 2nd days respectively. Figures 1 and 2 are the percentage rate of drying groundnut on the 1st and 2nd days respectively while Figure 3 is the temperature variation on the 1st day at different times of the day. Then Figures 4 and 5 are the percentage rate of drying sliced plantain on the 1st and 2nd days respectively while Figure 6 is the temperature variation on the 2nd day at different times of the day.

Table 1. Measurement for sample 1 (fresh groundnut) on the 1st day

Time (Hours)	Mass of 1A in (g)	Mass of 1B in (g)	Mass of 1C in (g)	Temp. of Oven 1 (°C)	Temp. of Oven 2 (°C)	Ambient Temp. (°C)
9.30 am	21.41	21.55	21.90	32.0	32.0	32.0
11.00 am	18.41	19.13	21.90	49.0	47.0	32.0
12.30 pm	14.20	15.35	20.48	57.0	54.0	38.0
2.00 pm	12.80	14.30	19.80	55.0	53.0	34.0
3.30 pm	9.80	13.30	17.76	42.0	41.0	30.0

Average percentage loss in mass was computed according to [9]

$$\frac{a-b}{a} \times 100\%$$

1

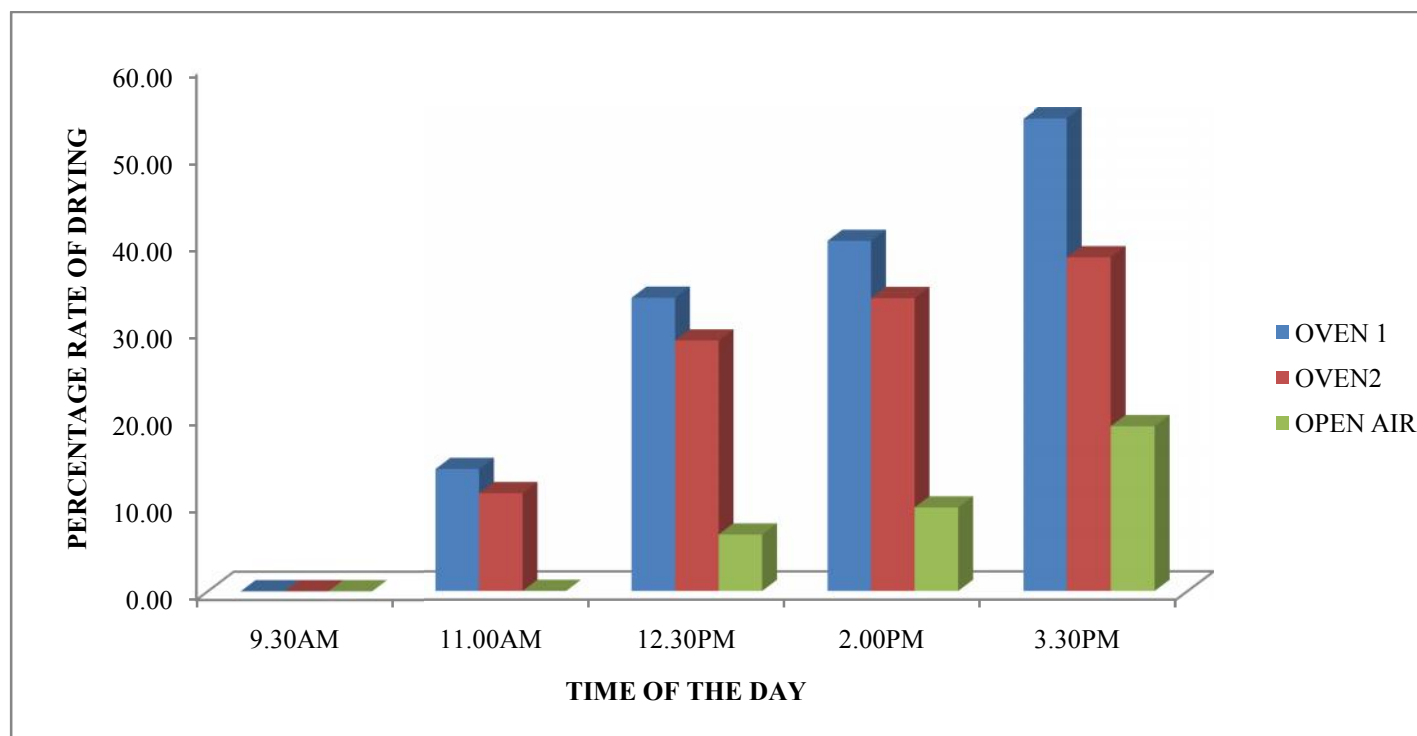
Where a = initial mass of the sample

165 b = final mass of the sample
 166 Then using equation 1, percentage loss in mass of sample 1A = 54.22%
 167 Percentage loss in mass of sample 1B = 38.28%
 168 Percentage loss in mass of sample 1C = 18.90%
 169

170 Table 2. Measurements for sample 1 (fresh groundnut) on the 2nd day.

Time (Hours)	Mass of 1A in (g)	Mass of 1B in (g)	Mass of 1C in (g)	Temp. of Oven 1 (°C)	Temp. of Oven 2 (°C)	Ambient Temp. (°C)
9.30 am	23.09	23.73	23.15	28.0	28.0	28.0
11.00 am	20.72	21.40	22.14	64.0	61.0	38.0
12.30 pm	18.94	19.57	20.69	59.0	56.0	37.0
2.00 pm	14.73	15.52	18.60	65.0	62.0	40.0
3.30 pm	10.31	13.51	17.90	49.0	47.0	30.0

171 Percentage loss in mass of sample 1A = 55.35%
 172 Percentage loss in mass of sample 1B = 43.07%
 173 Percentage loss in mass of sample 1C = 22.68%
 174



175
 176 Figure 3; The percentage rate of drying groundnut on the 1st day

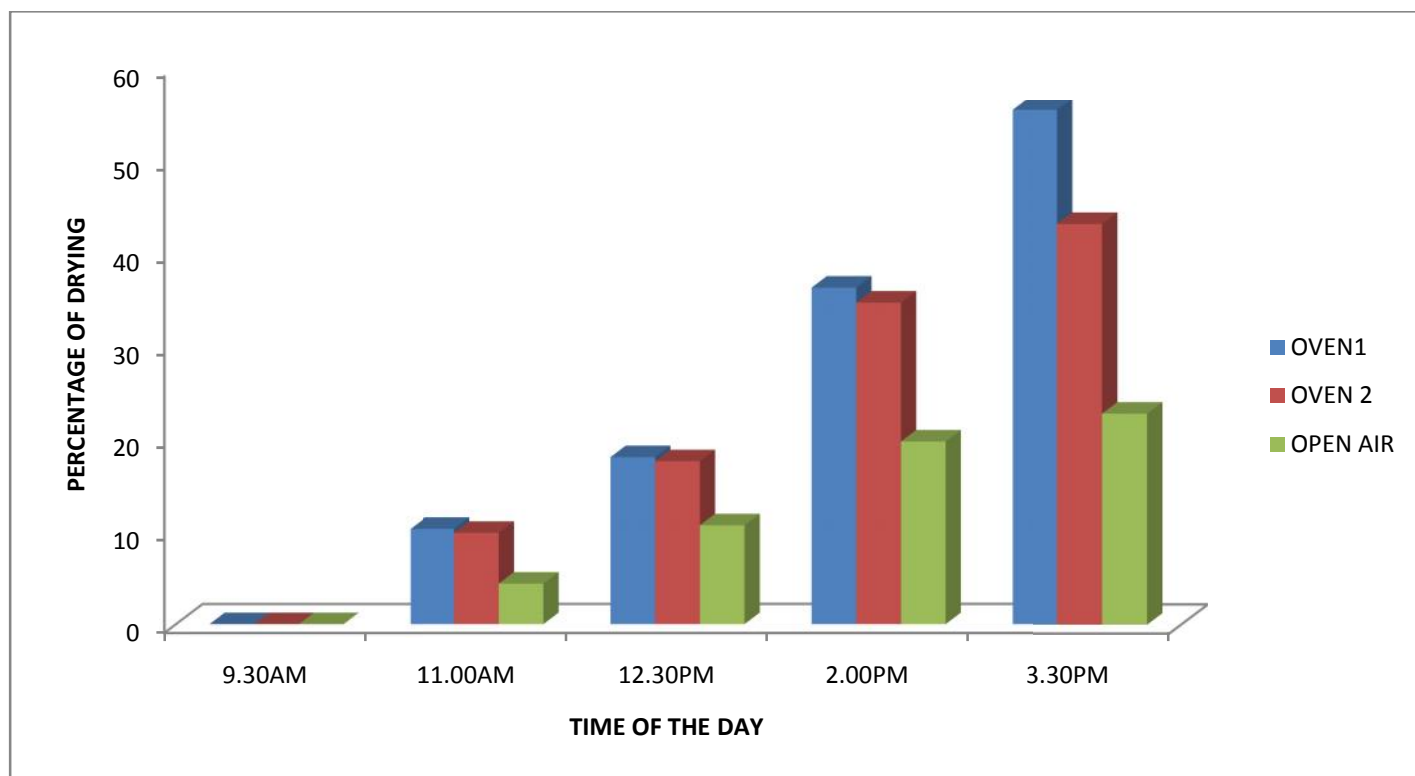


Figure 4: The percentage rate of drying groundnut on the 2nd day

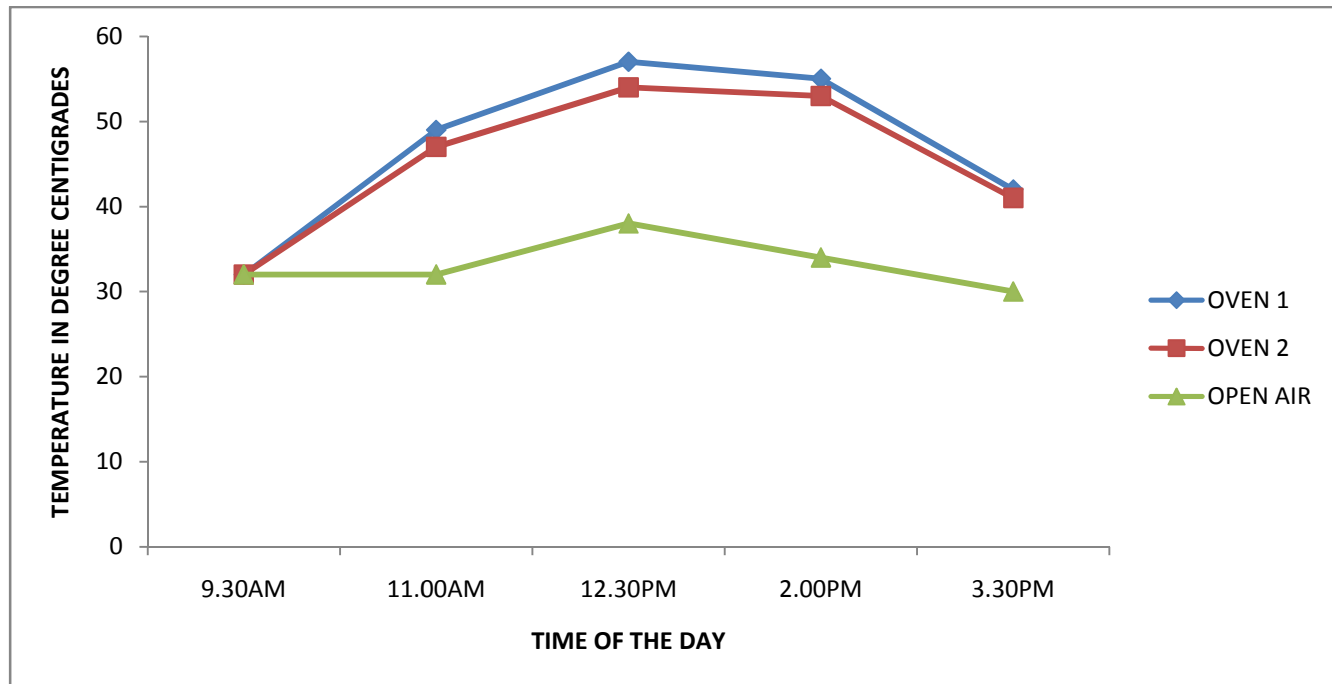


Figure 5. The plot of temperature variation against Time on the 1st day

182 Table 3. Measurements for samples 2 (Plantain) on the 1st day.

Time (Hours)	Mass of 2A in (g)	Mass of 2B in (g)	Mass of 2C in (g)	Temp. of Oven 1 (°C)	Temp. of Oven 2 (°C)	Ambient Temp. (°C)
9.30 am	22.61	23.54	20.18	32.0	32.0	32.0
11.00 am	16.81	20.60	18.61	49.0	47.0	32.0
12.30 pm	12.75	16.01	14.61	57.0	54.0	38.0
2.00 pm	10.57	13.19	13.02	55.0	53.0	34.0
3.30 pm	9.98	11.70	12.49	42.0	41.0	30.0

183

184 Percentage loss in mass of sample 2A = 55.86%

185 Percentage loss in mass of sample 2B = 50.30%

186 Percentage loss in mass of sample 2C = 38.11%

187

188

189 Table 4 Measurements for samples 2 (Plantain) on the 2nd day

Time (Hours)	Mass of 2A in (g)	Mass of 2B in (g)	Mass of 2C in (g)	Temp. of Oven 1 (°C)	Temp. of Oven 2 (°C)	Ambient Temp. (°C)
9.30 am	28.53	25.18	26.08	28.0	28.0	28.0
11.00 am	17.24	17.18	19.51	64.0	61.0	38.0
12.30 pm	14.41	13.47	17.16	59.0	56.0	37.0
2.00 pm	11.32	10.24	15.17	65.0	62.0	40.0
3.30 pm	10.91	10.23	14.28	49.0	47.0	30.0

190 Average percentage loss in mass of sample 2A = 61.76%

191 Average percentage loss in mass of sample 2B = 59.37%

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193 Average percentage loss in mass of sample 2C = 45.25%

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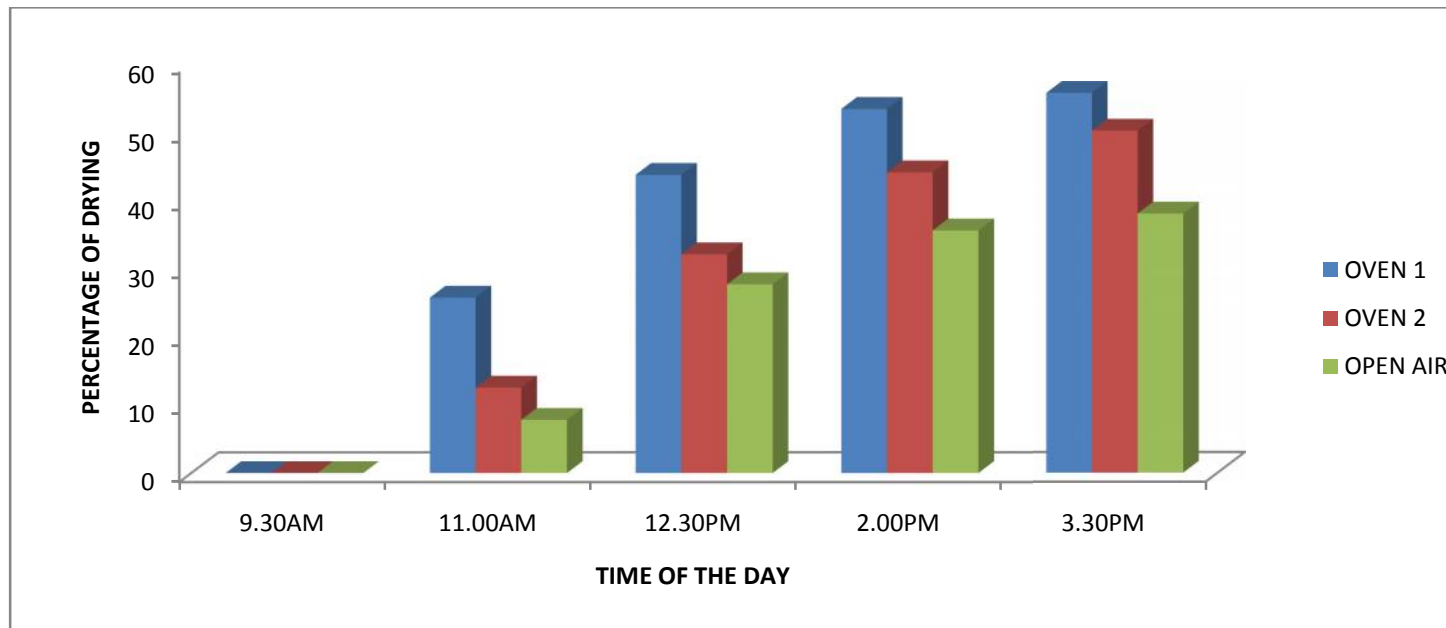


Figure 6 : The percentage rate of drying plantain on the 1st day

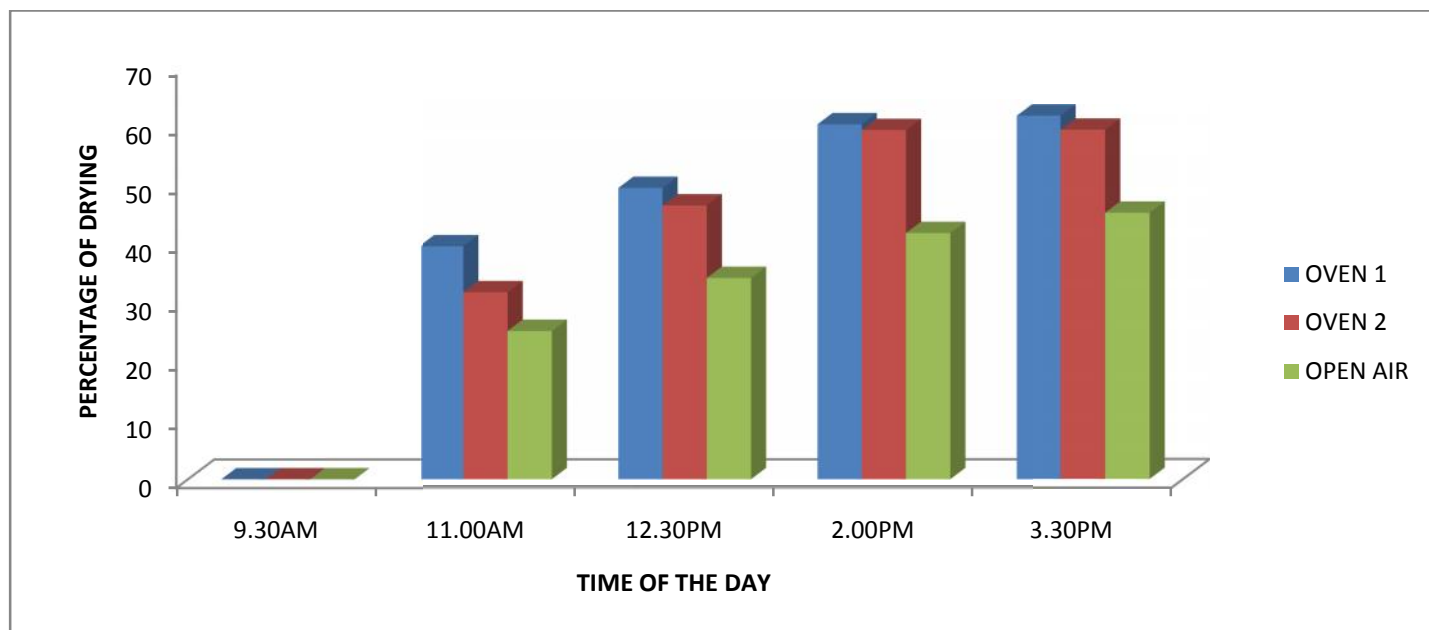


Figure 7: The percentage rate of drying plantain on the 2nd day

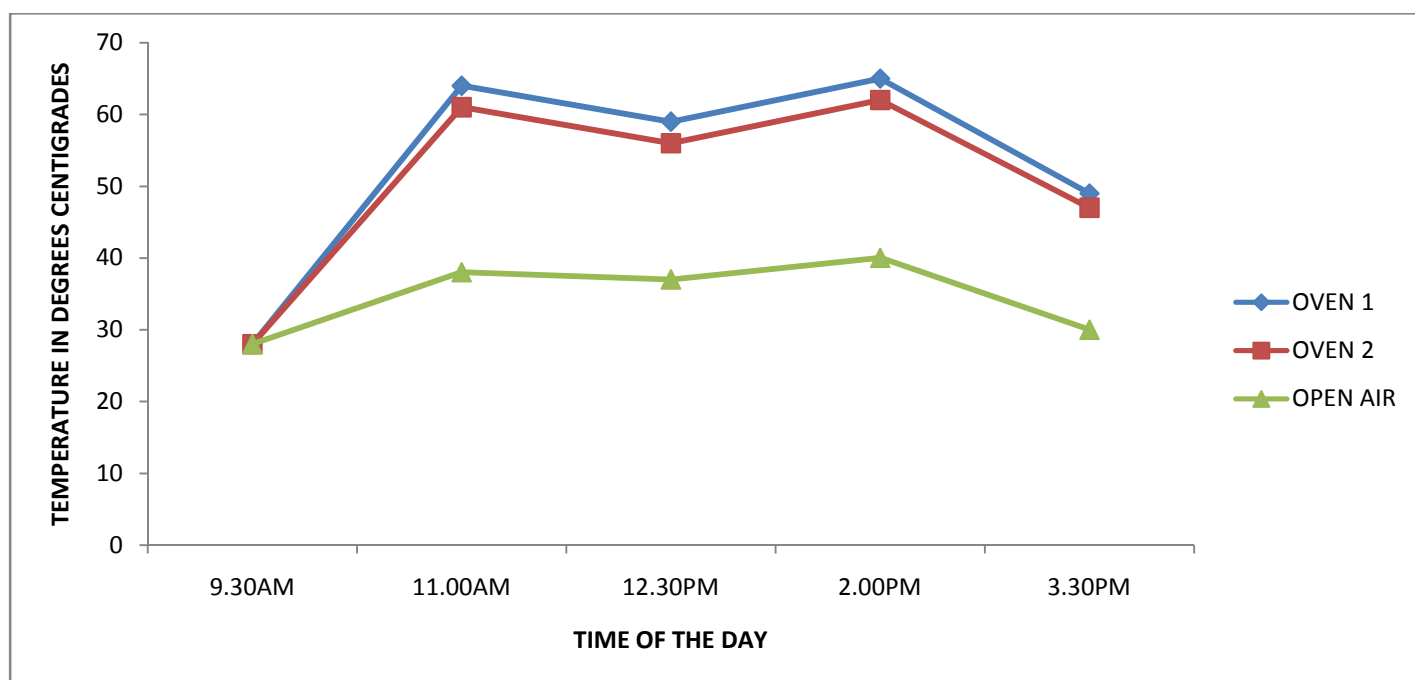


Figure 8: The plot of temperature variation against Time on the 2nd day.

Tables 5 and 6 shows the measurements recorded for fresh pepper on the 3rd and 4th days respectively. While tables 7 and 8 are the measurements recorded for sliced meat on the 3rd and 4th days respectively. Figures 7 and 8 are the percentage rate of drying fresh pepper on the 3rd and 4th days respectively while Figure 9 is the temperature variation on the 3rd day at different times of the day. Then Figures 10 and 11 are the percentage rate of drying sliced meat on the 3rd and 4th days respectively while Figure 12 is the temperature variation on the 4th day at different times of the day.

Table 5 Measurements for samples 3 (Pepper) on the 3rd day

Time (Hours)	Mass of 3A in (g)	Mass of 3B in (g)	Mass of 3C in (g)	Temp. of Oven 1 (°C)	Temp. of Oven 2 (°C)	Ambient Temp. (°C)
9.30 am	20.51	21.82	20.66	28.0	28.0	28.0
11.00 am	16.52	18.11	18.71	52.0	50.0	38.0
12.30 pm	12.21	13.20	15.42	57.0	54.0	39.0
2.00 pm	7.59	9.47	13.01	72.0	66.0	42.0
3.30 pm	5.51	7.08	11.63	56.0	53.0	35.0

Average percentage loss in mass of sample 3A = 73.14%

Average percentage loss in mass of sample 3B = 67.55%

Average percentage loss in mass of sample 3C = 43.71%

216

217 Table 6. Measurements for samples 3 (fresh pepper) 4th day

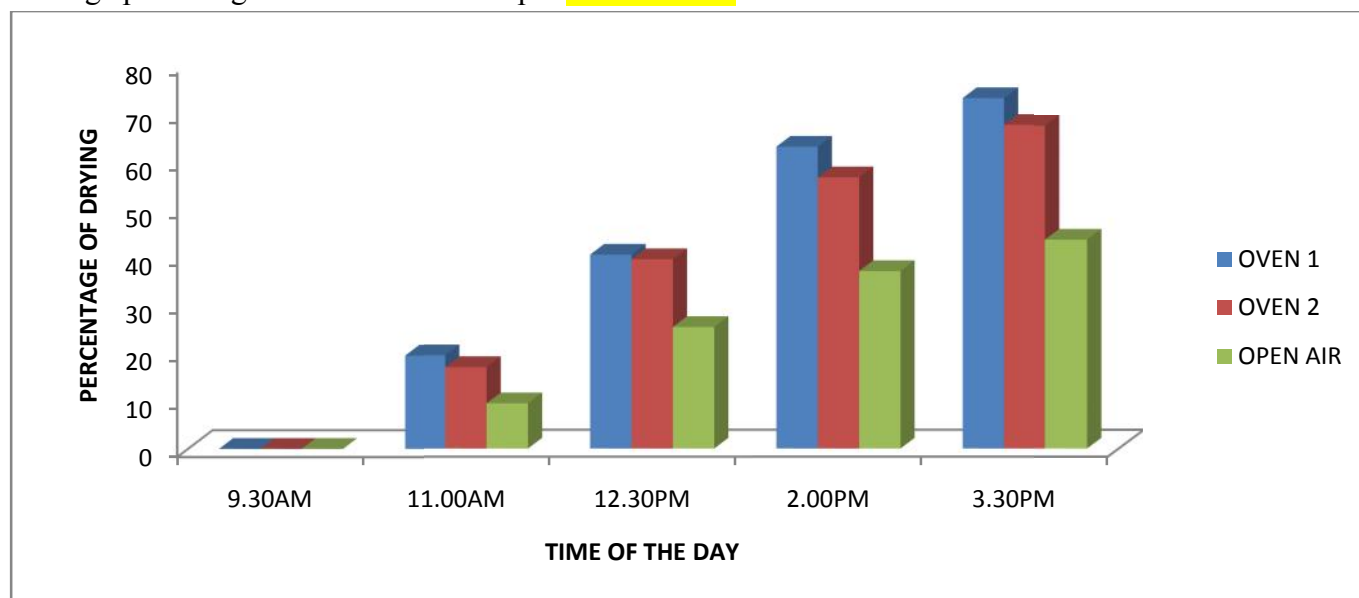
Time (Hours)	Mass of 3A in (g)	Mass of 3B in (g)	Mass of 3C in (g)	Temp. of Oven 1 (°C)	Temp. of Oven 2 (°C)	Ambient Temp. (°C)
9.30 am	24.21	23.70	23.97	31.0	31.0	31.0
11.00 am	14.48	14.91	16.77	67.0	62.0	38.0
12.30 pm	9.22	10.33	13.23	57.0	55.0	36.0
2.00 pm	5.31	8.19	10.86	73.0	65.0	45.0
3.30 pm	4.13	5.18	8.73	55.0	52.0	33.0

218 Average percentage loss in mass of sample 3A = 82.94%

219 Average percentage loss in mass of sample 3B = 78.14%

220

221 Average percentage loss in mass of sample 3C = 63.36%



222

223 Figure 9. The percentage rate of drying pepper on the 3rd day

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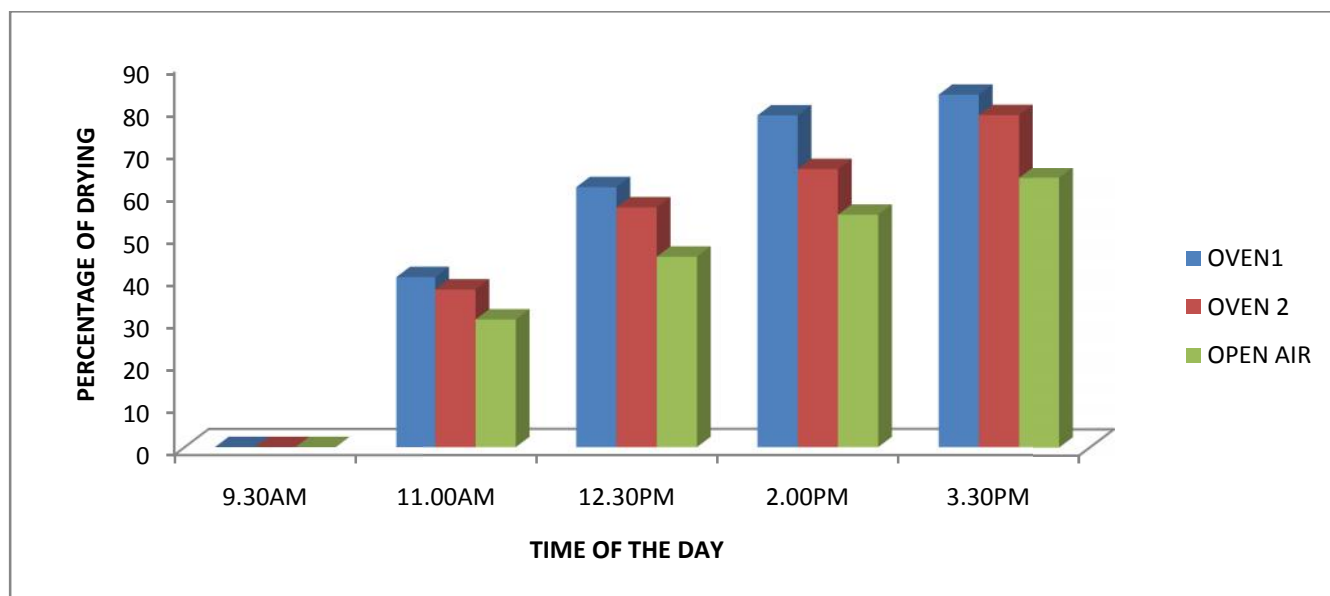


Figure 10: The percentage rate of drying pepper on the 4th day

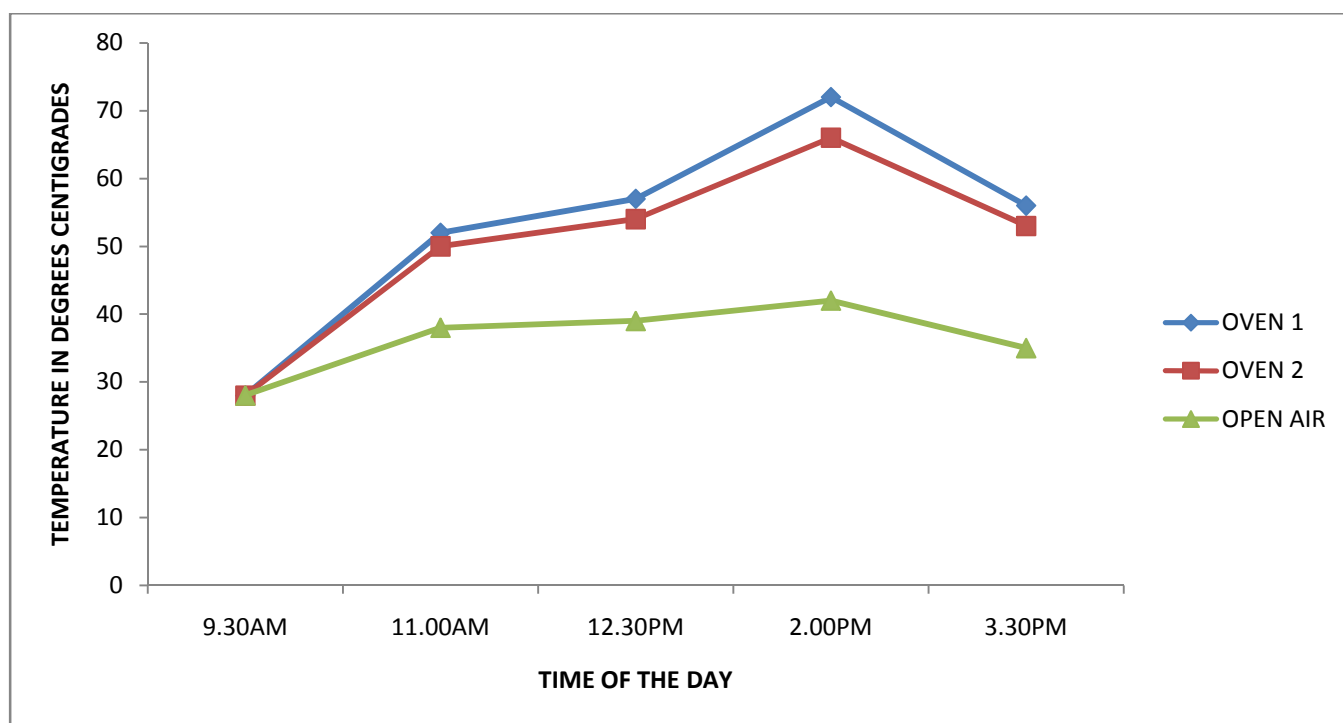


Figure 11: The plot of Temperature variation against Time on the 3rd day.

232 Table 7. Measurements for sample 4 (fresh Meat) on the 3rd day.

Time (Hours)	Mass of 4A in (g)	Mass of 4B in (g)	Mass of 4C in (g)	Temp. of Oven 1 (°C)	Temp. of Oven 2 (°C)	Ambient Temp. (°C)
9.30 am	21.79	22.48	22.17	28.0	28.0	28.0
11.00 am	17.62	18.23	18.18	52.0	50.0	38.0
12.30 pm	13.73	14.07	14.89	57.0	54.0	39.0
2.00 pm	9.81	10.41	11.67	72.0	66.0	42.0
3.30 pm	8.47	9.22	11.21	56.0	53.0	35.0

233 Average percentage loss in mass of sample 4A = 61.13%

234 Average percentage loss in mass of sample 4B = 58.99%

235 Average percentage loss in mass of sample 4C = 49.44%

236

237 Table 8. Measurements for sample 4 (fresh meat) on the 4th day

Time (Hours)	Mass of 4A in (g)	Mass of 4B in (g)	Mass of 4C in (g)	Temp. of Oven 1 (°C)	Temp. of Oven 2 (°C)	Ambient Temp. (°C)
9.30 am	29.61	28.08	28.51	31.0	31.0	31.0
11.00 am	23.16	23.61	26.18	67.0	62.0	38.0
12.30 pm	17.14	18.96	24.88	57.0	55.0	36.0
2.00 pm	13.78	16.21	22.09	73.0	65.0	45.0
3.30 pm	11.89	13.62	20.83	55.0	52.0	33.0

238 Average percentage loss in mass for sample 4A = 59.85%

239 Average percentage loss in mass for sample 4B = 51.50%

240 Average percentage loss in mss for sample 4C = 26.94%

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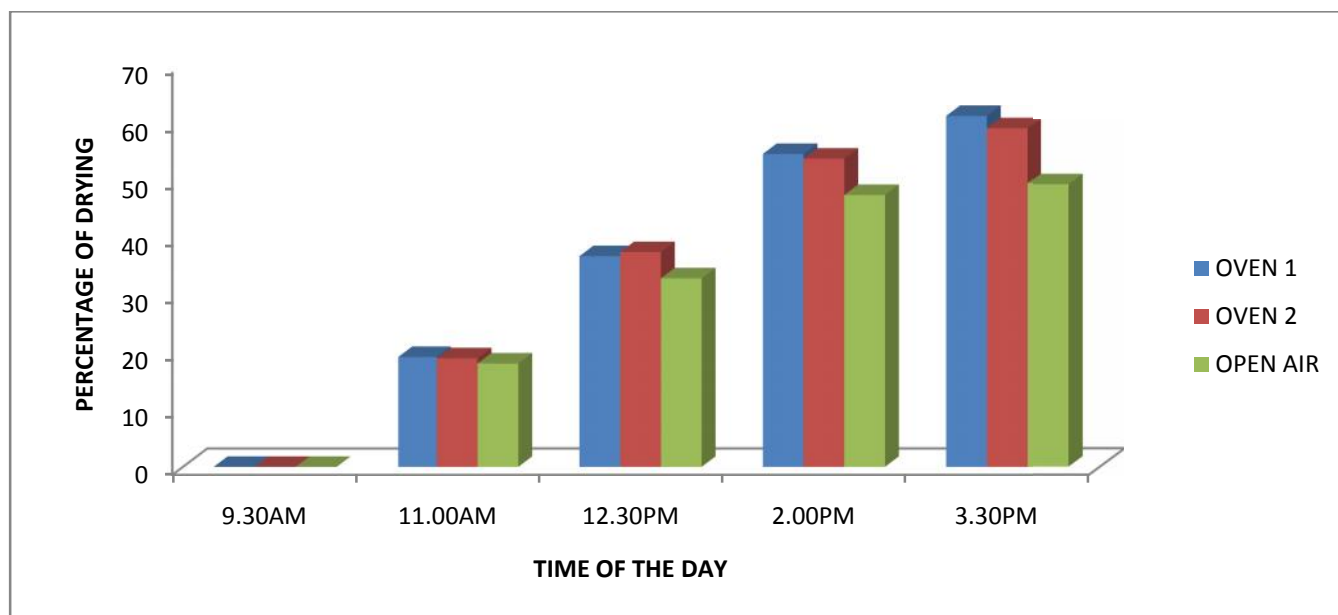


Figure 12: The percentage rate of drying fresh meat on the 3rd day

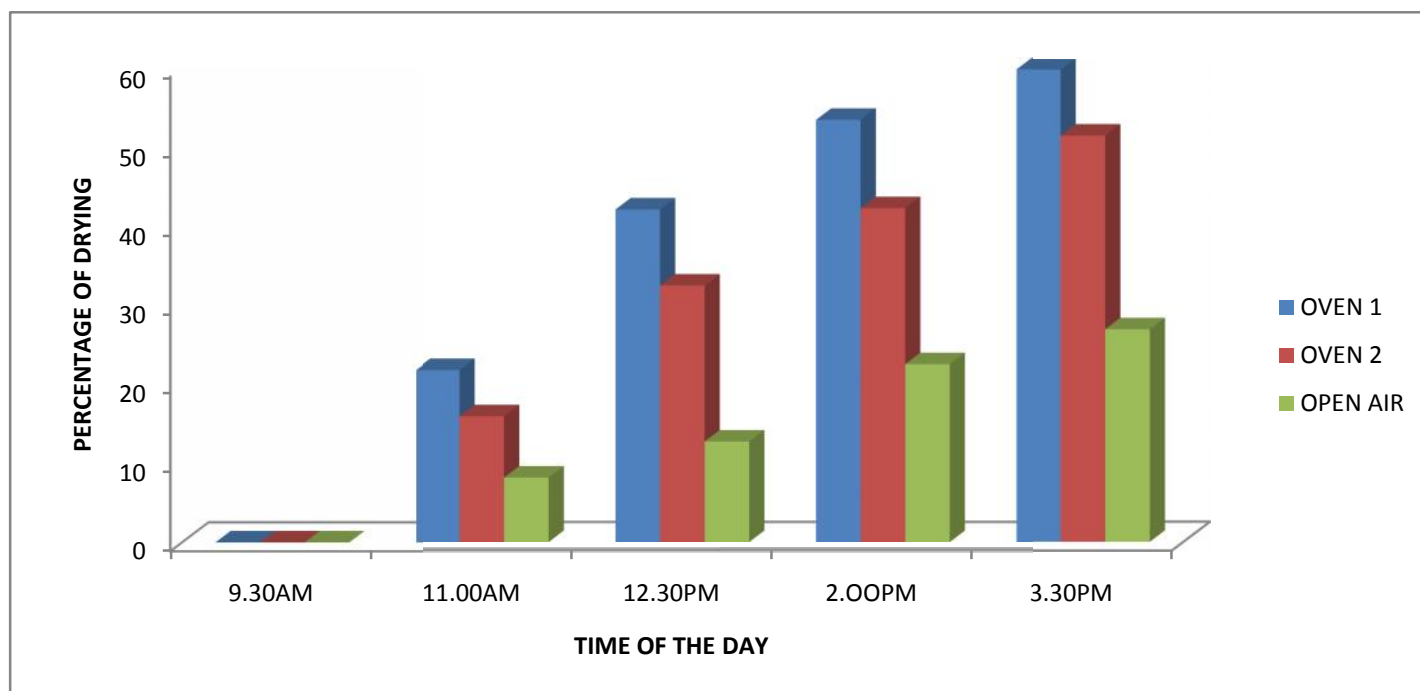


Figure 13: The percentage rate of drying fresh meat on the 4th day

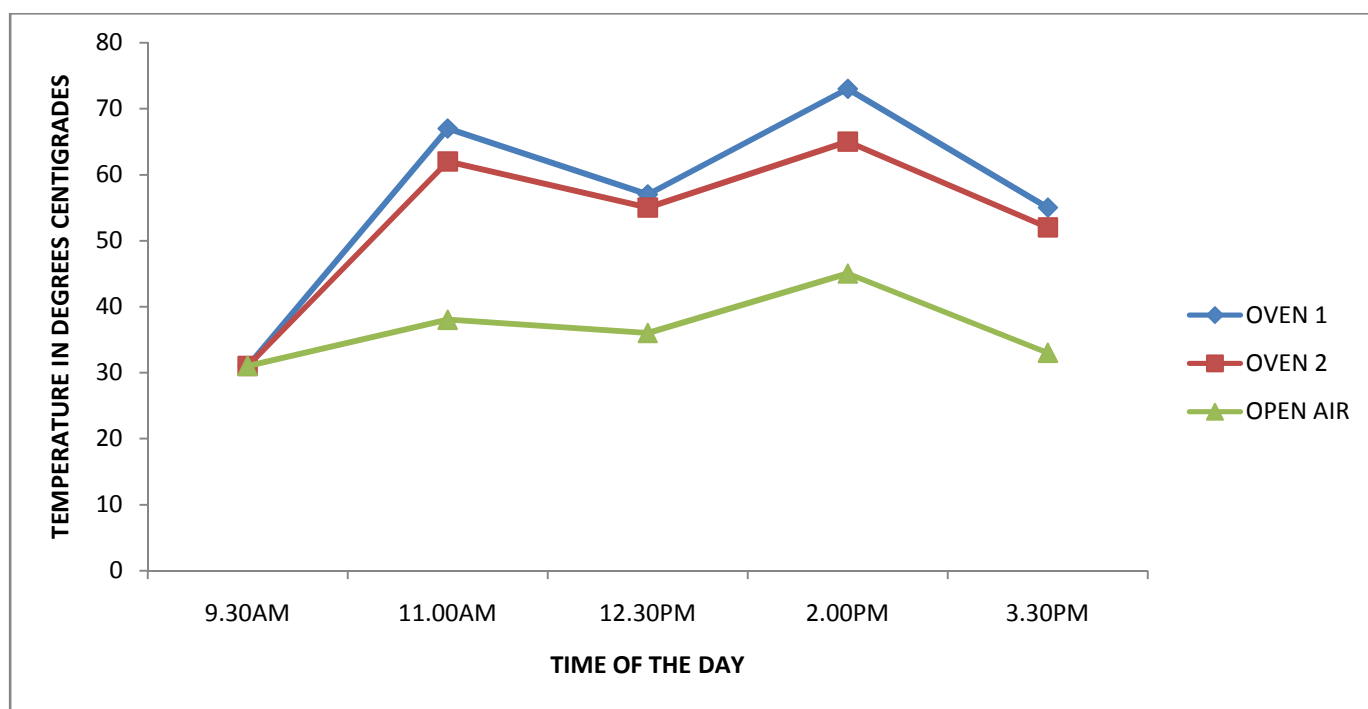


Figure 14: The plot of Temperature variation against Time on the 4th day

Tables 9 and 10 are the measurements recorded for sample 5 (fresh fish) on the 5th and 6th days respectively. Figures 13 and 14 are the percentage rate of drying fresh fish on the 5th and 6th days respectively. While Figures 15 and 16 are the plot of the temperature variation on the 5th and 6th days respectively at different times of the day.

Table 9. Measurements for sample 5 (fresh fish) on the 5th day

Time (Hours)	Mass of 5A in (g)	Mass of 5B in (g)	Mass of 5C in (g)	Temp. of Oven 1 (°C)	Temp. of Oven 2 (°C)	Ambient Temp. (°C)
9.30 am	21.63	22.93	21.83	28.0	28.0	28.0
11.00 am	17.82	19.31	19.16	52.0	50.0	38.0
12.30 pm	14.33	15.29	17.51	72.0	54.0	39.0
2.00 pm	11.56	12.66	14.81	71.0	66.0	42.0
3.30 pm	5.73	8.71	12.84	56.0	53.0	35.0

Average percentage loss in mass for sample 5A = 73.51%

Average percentage loss in mass for sample 5B = 62.02%

Average percentage loss in mass for sample 5C = 41.18%

Table 10. Measurements for samples 5 (fresh fish) on the 6th day

Time (Hours)	Mass of 5A in (g)	Mass of 5B in (g)	Mass of 5C in (g)	Temp. of Oven 1 (°C)	Temp. of Oven 2 (°C)	Ambient Temp. (°C)
9.30 am	20.47	20.82	21.41	31.0	31.0	31.0
11.00 am	14.88	15.43	16.25	67.0	62.0	38.0
12.30 pm	11.92	12.22	13.77	79.0	74.0	45.0
2.00 pm	9.01	10.42	12.64	73.0	65.0	42.0
3.30 pm	7.15	9.98	11.60	55.0	52.0	32.0

Average percentage loss in mass for sample 5A = 65.07%

Average percentage loss in mass for sample 5B = 52.07%

Average percentage loss in mass for sample 5C = 45.82%

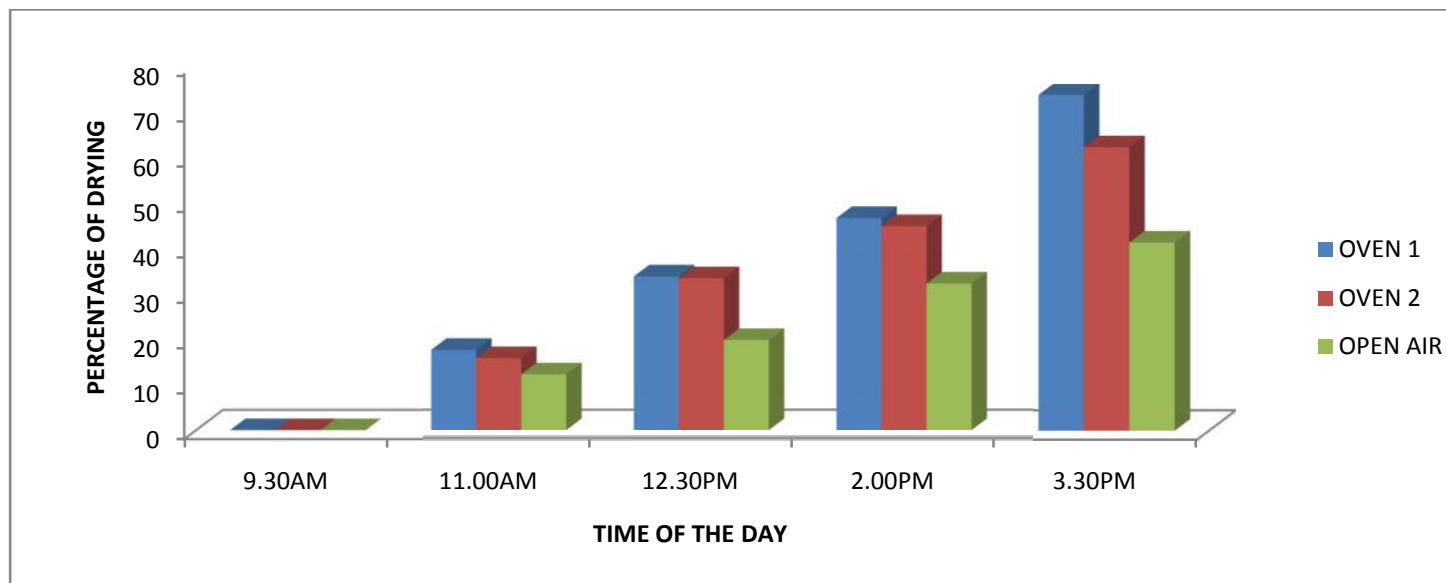


Figure 15: The percentage rate of drying fresh fish on the 5th day

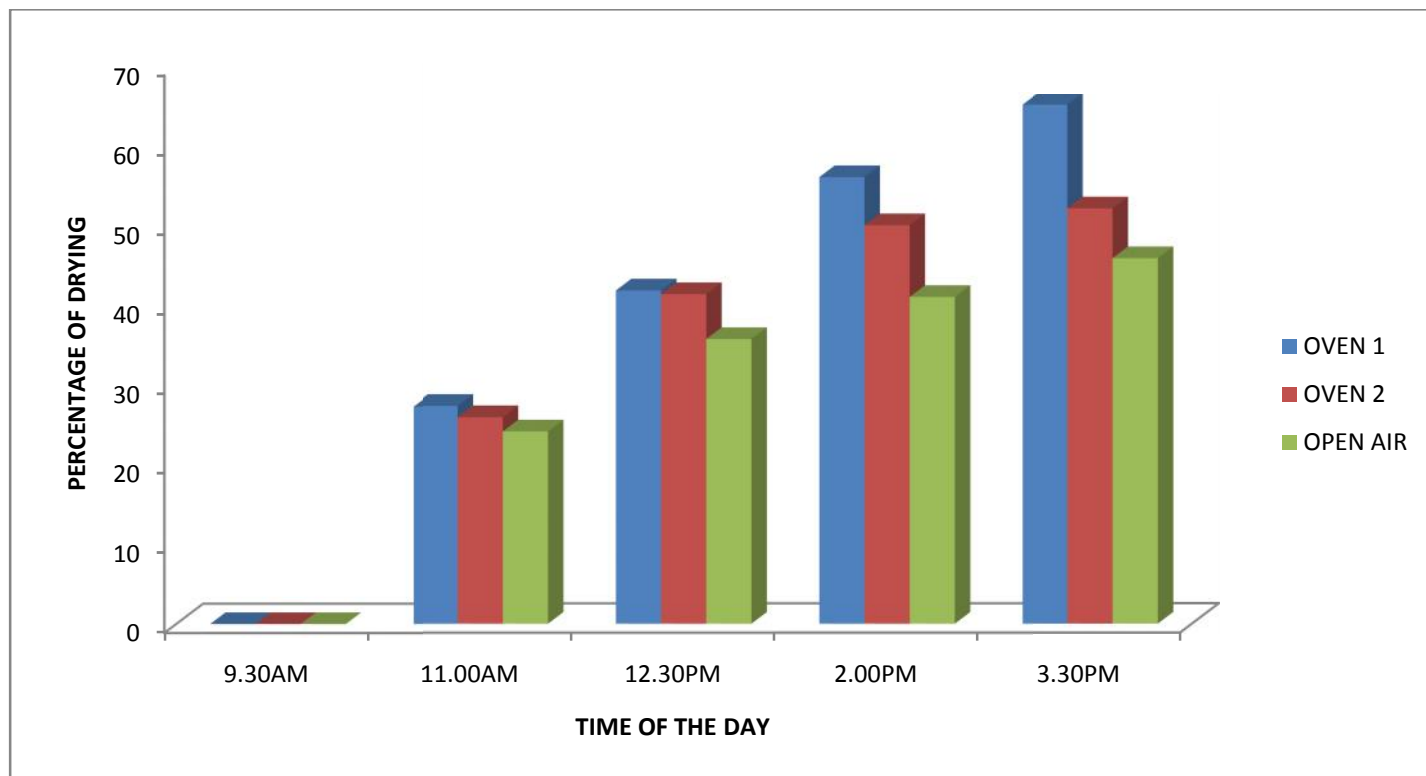


Figure 16: The percentage rate of drying fresh fish on the 6th day

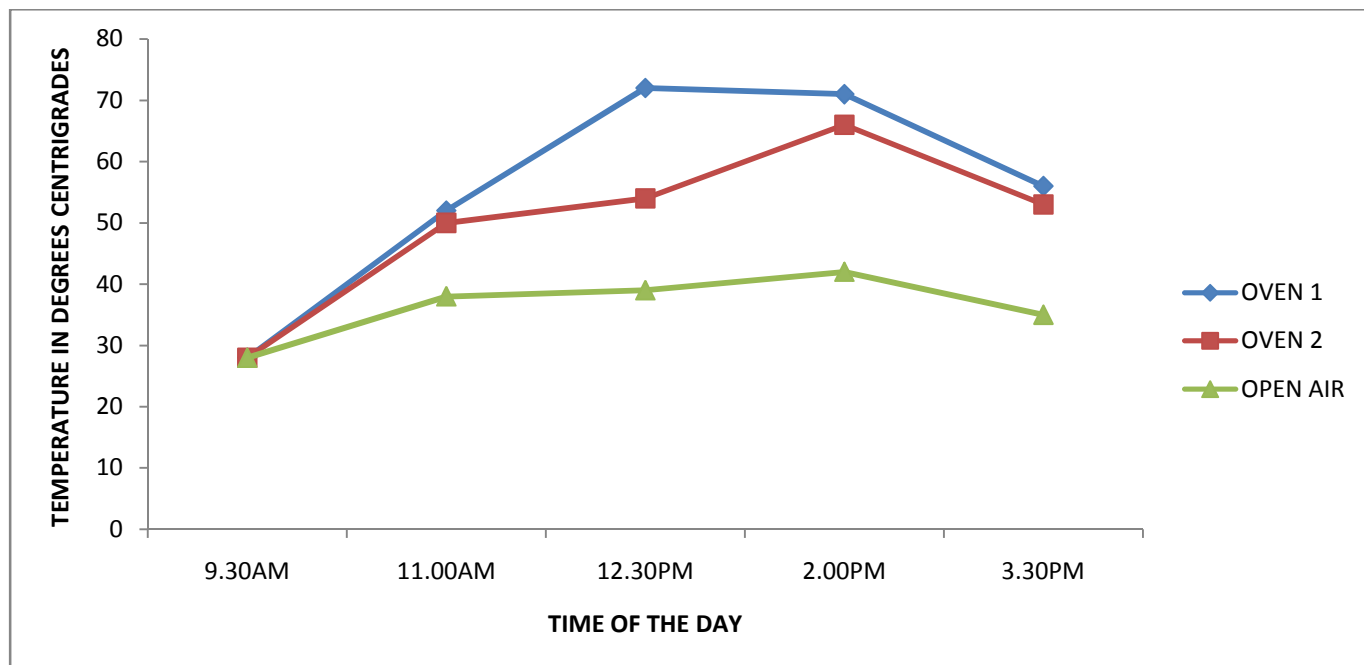


Figure 17: The plot of Temperature against Time on the 5th day

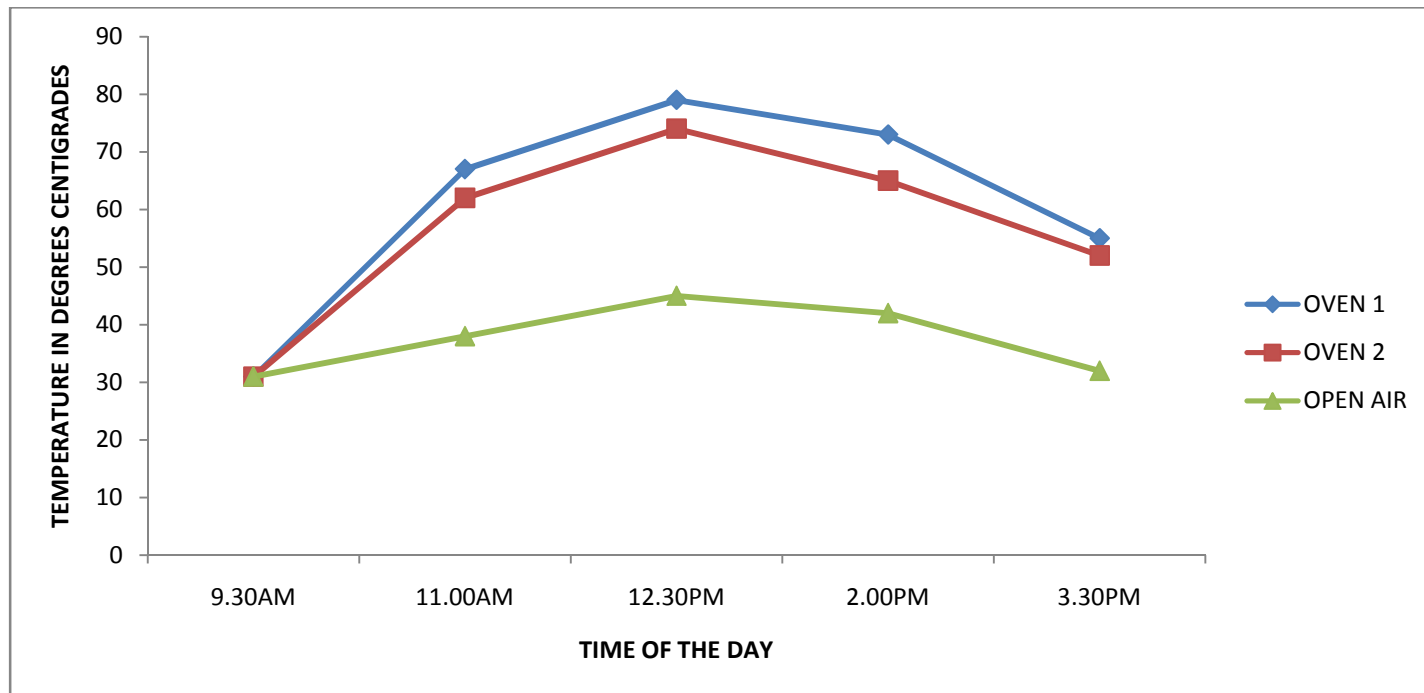


Figure 18: The plot of temperature against Time on the 6th day

Ovens 1 was able to cook egg for **three hours thirty minutes (3.30 hours)** at an average temperature of 68 °C, while oven 2 could cook a similar egg with the same mass for about **four hours twenty minutes (4.20 hours)** at an average temperature of 62 °C.

4.0 The power capacity of the solar dryers

The power capacities of the solar dryers were calculated using the Stefan – Boltzmann formula as stated by [10] in equation 2 as follows:

$$W = Ae\delta T^4 \quad 2$$

Where W = the power in watts

A = the surface area of the material in m²

E = the emissivity which depends on the nature of the surface. It is also equal to the absorptivity defined as

$$\sigma = \frac{\text{Radiation energy absorbed by surface}}{\text{Radiation energy incidence on the surface}}$$

The value of a is between 0 and 1. Surfaces where $\sigma = 1$ are the best absorbers as well as the best emitters of radiation at the same temperature. Hence a surface with $\sigma = e = 1$ is a black body. That was why the aluminum plate was painted black so that radiation energy incidence on the surface will be equal to the radiation energy absorbed by the surface.

δ = Stefan – Boltzmann constant ($5.7 \times 10^{-8} \text{ Js}^{-1}\text{m}^2\text{C}^{-4}$)

T = the absolute in Kelvin.

For Oven 1, the highest temperature recorded is $79^\circ\text{C} = 352\text{K}$.

The surface area of the oven = $(80 \times 50) \text{ cm}^2 = (80 \times 50) \times 10^{-4} \text{ m}^2$

Therefore the power is given as

$$W = 80 \times 50 \times 10^{-4} \times 1 \times 5.7 \times 10^{-8} \times 352^4 = 350.00\text{W} \quad 3$$

For oven 2, the highest temperature recorded is $74^\circ\text{C} = 347\text{K}$.

Therefore the power is given as:

$$W = 80 \times 50 \times 10^{-4} \times 1 \times 5.7 \times 10^{-8} \times 347^4 = 330.56\text{W} \quad 4$$

For the open drying, the highest temperature was $45^\circ\text{C} = 318\text{K}$

Therefore the power is given as

$$W = 80 \times 50 \times 10^{-4} \times 1 \times 5.7 \times 10^{-8} \times 318^4 = 233.15\text{W} \quad 5$$

5.0 Discussion

From the results obtained above, Figures 3, 4, 6, 7, 9, 10, 12, 13, 15, and 16 shows that the rate of drying in the oven with reflector is higher than that without reflector. These are much higher than the open air – drying. Then the variations of temperature in the two ovens and the open air as shown in Figures 5, 8, 11, 13, 17 and 18, also reveals that the temperature inside the oven with reflector was higher than the one without reflector. Moreover, both are higher than the ambient temperature in all cases. In the course of this research work, the highest temperature recorded for the oven with reflector is 79°C , while the oven without reflector recorded 74°C . The highest ambient temperature recorded on the hottest day was 45°C . The difference between the power output of the two dryers and that of the open air is about 100W.

6.0 Conclusion.

In summary, the solar cabinet dryers were constructed to convert solar energy into heat energy for domestic purposes. The one with mirror reflectors gave higher temperature, efficiency of drying and power output than the one without the mirror reflectors. Both could reduce the water

content of products like groundnut and corn to preserve them for future planting. Fresh fish, meat and pepper dried in this project could be preserved for any length of time. Most importantly, it has been shown that these dryers could conveniently cook an egg without much labor. It is easy to construct and maintain, and its construction materials are readily available in the local market. This prototype dryers when mass – produced, could act as an alternative dryer to the conventional means of drying and sometimes cooking for rural farmers in Nigeria and tropical countries with similar circumstances.

6.0 References

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