Design and Construction of a Solar Dryer for Drying of Maize Seeds

Sule Salisu[1], Akene Alexander[2], Oghenevwaire Iyabo Seyefa [3]

[1]Department of Mechanical Engineering, Petroleum Training Institute, Effurun, Nigeria
[2,3]Department of Mechanical Engineering, Federal University of Petroleum Resources, Effurun, Nigeria

Abstract: - **The use of solar thermal systems (especially in the agricultural sector, to conserve vegetables, fruits, coffee and other crops) has shown to be practical, economical and the responsible approach environmentally. Solar heating systems to dry food and other crops can improve the quality of the product, while reducing wasted produce and traditional fuels - thus improving the quality of life, however the availability of good information is lacking in many of the countries where solar food processing systems are most needed. This research work is therefore focused on the design and construction of a solar dryer for drying of maize seed. In designing of the solar seeds dryer, proper design considerations such as functionality, cost, and availability of materials were taken. The solar seeds dryer consists of the following major components; solar collector, drying chamber, transparent cover (glass), and the absorber plat. The solar seed dryer has a cross sectional area of 1000 mm x 1000 mm (1m^2). The front of the box was measured and cut to 320 mm in height and 1000 mm in length. A vent was cut in the front measuring 30 mm in height and 600 mm in length. The solar seed dryer was evaluated for performance and the results obtained showed that during no-load test, average temperature of the heated air inside the solar dryer was higher than the average ambient temperature. It was also observed that large quantity of moisture content was removed throughout the three days. However, it was highest in day one, and least in day 2.**

Keywords: **Solar dryer, moisture content, temperature, drying time, maize seeds**

I. INTRODUCTION

Drying of Agricultural produces preserve it by removing enough moisture from it mainly to prevent decay and spoilage. However, over the year, the use of fire wood is common phenomena especially among the rural populace. The bulk of the energy used for cooking, heating and drying for most households in Nigeria is mainly derived from wood fuel [1-7].As a result of this, Nigeria's forests, which currently extend over 9.6 million hectares, have been dwindling rapidly over the past decades [8-9]. Thus, the rate of deforestation in Nigeria was estimated at 3.7%, which is one of the highest in the world as reported by the United Nation Collaborating Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Country [10]. Also, considering the abundance of sunlight, the present energy crises facing the world's industrial and technological sector, and global warming caused by greenhouse effect when fossil fuels like firewood, coal, oil and gases are burnt; thus, it is essential to preserve the Agricultural produce using any a preservation techniques that is environmental friendly and equally sustainable.

As such, seeds of maize can be dried by solar dryer in order to save the part of the production that will not be readily consumed, since drying is a classical method of preservation, which provides an extension of shelf-life, lighter weight for transportation and less space for storage.

Furthermore, a solar drying technology offers a big challenge for minimizing these losses at low cost and it is the only non-polluting, inexhaustible energy resource that can be utilized economically to supply man's energy needs [11]. Solar food dryers represent a major improvement upon this ancient method of dehydrating foods. Although solar dryers involve an initial expense, they produce better looking, better tasting, and more nutritious foods, enhancing both their food value and their marketability. They are equally faster, safer, and more efficient than traditional sun drying techniques [12]. An enclosed cabinet-style solar dryer can produce high quality, dried foodstuffs in humid climates as well as arid climates. It can also reduce the problem of contamination. Drying is completed more quickly, so there is less chance of spoilage. Besides, solar dryers have no additional fuel cost and this method of preserving food also conserves non-renewable sources of energy [13].In recent years, attempts have been made to develop solar dryers that can be used in agricultural activities in developing countries. Many of the dryers used for dehydrating foods are relatively low-cost compared to systems used in developed countries.

II. RESEARCH METHODOLOGY

2.1 Design Factors

The following factors were considered in designing the Agro solar seed dryer;

i. Functionality
ii. Aesthetics
iii. Overall size
iv. Availability
v. Serviceability
vi. Cost

Functionality

The system should be able to absorb solar energy from the sun and use the energy to heat up the seeds in the drying chamber by natural convection. The collector is designed to heat the air in the drying chamber where it is used to dry the seeds. The solar rays enter the cabinet through the cover material. When reaching the solar collector or the tray surface, they are converted into heat energy, raising the temperature inside. The heat energy is transferred to the seeds to be dried. The heated Agro seeds give out water vapour and dries up. Gradually, the heated moist air goes up and leaves the drying chamber through the air outlet at the high end of the drier.

Aesthetics

The solar seed dryer is designed in such a way that its appearance is attractive. The wood was varnished to prevent decay and also to make the wood look attractive. The device is incorporated with rollers (tyres) and handles for easy movement and handling (ergonomics).

Overall Size

The length, width and height of the solar seed dryer are such that it can be easily carried about. It was designed to be portable.

Accessibility

The system is designed in such a way that every component can be locally fabricated and replaced at low cost. All the parts should be available locally and at low cost.

Serviceability

The system is designed in such a way that faults or defects can be easily detected and rectified at low maintenance cost.

2.2 Components of the Agro Solar Seed Dryer

The solar seed dryer was made mainly of wood and consisted of the following major components:

i. The solar collector
ii. Drying chamber (heat storage chamber)
iii. The transparent cover (glass)
iv. The absorber plate

Transparent Cover (Glass)

The main function of the glass cover is to create greenhouse effect. Glass is highly transparent to the sun's short wave radiation but completely opaque to the long wave radiation emitted by the heated collector plate. It is also unaffected by the sun's ultraviolet radiation which is highly destructive to most plastic films.

Absorber Plate

The absorber plate is corrugated aluminium blackened to convert the incoming shortwave radiation into heat. It absorbs both direct and diffusion radiation. The surface has high absorptions for solar radiation and low emission for long wave radiation. Corrugated aluminium plate, blackened with dull paint, for instance, containing carbon black or graphite is recommended in this design because it has large surface exposure to the radiant energy and the cost is considerable and its thermal conductivity is high. Silver and copper are better materials but they are costly and scarce.

The Solar Collector

The solar collector is basically a top-open, wooden box made from thick vernier. The collector was inclined to keep its top surface, covered with 2.5 mm thick glass, at about 15 degrees to the horizontal. Heat losses to the outside through collector cover system depend mainly on:

i. Mean temperature of the absorber plate.
ii. Ambient temperature
iii. Absorption of the incoming radiation in the cover
iv. Intensity of the solar radiation

The following assumptions were considered in developing the solar collector;

i. Performance is steady state
ii. Headers cover a small area of collector that can be neglected
iii. One dimensional heat flow through the cover and back insulation
iv. Negligible temperature drop across the cover
v. The sky is considered as a black body for long-wave radiation at an equivalent temperature as the surrounding.
vi. Losses through front and back of the collector are to the same ambient temperature
vii. Dust and dirt on the collector are negligible
viii. Shading of the collector absorbing plate is negligible

The Drying Chamber

The drying chamber is made of wood (vinyl wood). The drying chamber is designed such that it permits hot dry air from the absorber plate to dehydrate the seeds and permit the exit of the resulting damp air through the outlet vents. The drying chamber has an opening which can be locked or opened with a hinged door provided.

Air Inlet (Vent)

This allows the entry of clean natural convection into the system in order to aid drying. The air inlet vent is covered with netting to prevent dust and predators from entering the collector.

Air Outlet

This is an opening which allows airflow from the drying chamber to the atmosphere. The heated moist air goes up and leaves the drying chamber through the air outlet at the high end of the dryer

Wire Gauze

This is where the seeds to be dried are spread. The seeds being dried are put on the wire gauze so that heated air from the collector can easily pass through the gauze and consequently cause drying. The wire gauze is of mild steel material and has high resistance to corrosion.

Sealing

This is used to line the sides of the glass in order to prevent it having contact with the wood. Rubber is used as the sealing material.

Netting

The net is placed at both ends (inlet and outlet) to protect against the insects and rodents which may affect the seeds being dried. It is made up of plastic material and cannot be corroded or destroyed easily.

2.3 Selection of Materials for the Solar Seed Dryer

In the selection of materials, the suitability to environmental conditions and mechanical stresses in which they will be subjected to were carefully thought out. In order to meet with requirement, a survey was carried out and it was found that the materials for the construction of the solar seed dryer were available and at a low cost. The following materials were therefore selected for the construction of the solar seed dryer.

i. Glass
ii. Wood
iii. Netting
iv. Handles
v. Hinges, hook
vi. Aluminum plate/foil
vii. Nails, gum, brush
viii. Paint/varnish
ix. Mesh
x. Screws
xi. Corner braces

2.4 Design Calculations

The dryer was designed using maize seeds sample and the following parameters were considered:

Average mass of each maize seeds = 0.4kg

Number of maize seeds = 30 cobs

Total mass of maize seeds $= 30 \times 0.4 = 12\ kg$

Drying period required was 8 hours for three consecutive days

Thus;

$$Drying\ period\ required = 8\ hrs\ \times 3 = 24\ hours$$

Density of maize = 824kg/m^3

Moisture content of maize at harvest = 20%

Expected moisture content after drying = 13%

Average ambient temperature (Ta) = 27^{o}C (300K)

Relative humidity (RH) = 80%

Height below bed of dryer (h_1) = 0.2m

Height above bed of dryer (h_2) = 0.4m

Atmospheric pressure = 101.3kpa

Gravitational acceleration (g) =9.81m/s

Temperature of air below the bed (Tp) = 44^{o}C (317K)

Temperature of air above the bed (Ts) = 32^{o}C (305K)

To calculate the pressure drop across the bed

Characteristic gas constant, R = 0.287kJ/kgk

$$\rho = \frac{101.3}{(0.287 \times 300)} = 1.177\ kg/m^3$$

$$\rho_1 = \frac{101.3}{(0.287 \times 317)} = 1.113\ kg/m^3$$

$$\rho_2 = \frac{101.3}{(0.287 \times 305)} = 1.157\ kg/m^3$$

Therefore, pressure drop across the bed ΔP,

$$\Delta P = [0.2(1.77 - 1.113) + 0.4(1.177 - 1.157)]9.81$$
$$= 0.204 N/m^2$$

The mass of moisture content removed per 12 kg of wet maize was obtained as;

$$= \frac{12(0.2 - 0.13)}{1 - 0.13)} = 0.966\ kg$$

From psychometric chart, the humidity ratio increases from 0.018 kg to 0.024 kg per kg of dry air was calculated as;

$$Mass\ of\ Air = \frac{Mass\ of\ moisture\ to\ be\ removed}{Increase\ in\ humidity\ ratio}$$
$$= \frac{0.97}{(0.024 - 0.018)} = 161.7\ kg$$

$$Mass\ of\ Aflow\ rate\ of\ air = \frac{161.7}{(24 \times 60)}$$
$$= 0.112\ kg/min$$

Therefore, the quantity of heat required to remove moisture content Q_i

$$Q_i = 0.966 \times 4.182 \times 17 = 68.68\ kJ$$

The useful heat energy (Q_u) is calculated as follow;

$$Q_u = 0.9[(470 \times 0.89) - 7.38(44 - 27)] = 207.5\, watts$$

Under steady state, the energy falling on the collector is distributed into useful gain at the absorber plate and various losses. That is;

$$Energy = Q_u + Q_{Losses}$$

Therefore if it is assumed that energy lost due to absorption, scattering, reflection and refraction etc., is 20%

$$Energy = 207.5 + 0.20 = 207.7\, watts$$

$$A_c = \frac{207.7}{200} = 1.00\, m^2$$

2.5 Construction Procedures

The solar seed dryer has a cross sectional area of 1000 mm x 1000 mm ($1m^2$). The front of the box was measured and cut to 320 mm in height and 1000 mm in length. A vent was cut in the front measuring 30 mm in height and 600 mm in length. Then the back of the box was measured and cut. The back of the box with an overall height of 700 mm and a length of 1000 mm was measured and cut. The back of the box also has a vent of 30 mm in height and 600 mm in length cut. A door measuring 500 mm by 100o mm was constructed and hinged. The sides also were cut and the four sides where joined to form a box with an open top. The air vents were covered with net in front to prevent insects from attacking the seeds and was covered with wire gauze on the inside to prevent rodents from attacking the seeds. The solar collector was spray-painted with black paint and a hole was cut in it to allow air flow through the collector to the screen or gauze where the seeds will be spread for drying. The solar collector was inclined at an angle of 15^0 to the horizontal. The interior of the dryer was painted black in other to retain heat. The gauze or screen (which will hold the seeds) measuring 1000 mm by 1000 mm was cut, reinforced with wood to prevent sagging and was slid into the box. The glass measuring 1000 mm by 1000 mm was then fixed on top of the box and handles and legs were fixed to complete the construction of the solar dryer. Figure 1 shows the isometric view of the solar dryer. Figure 2 shows the constructed solar dryer.

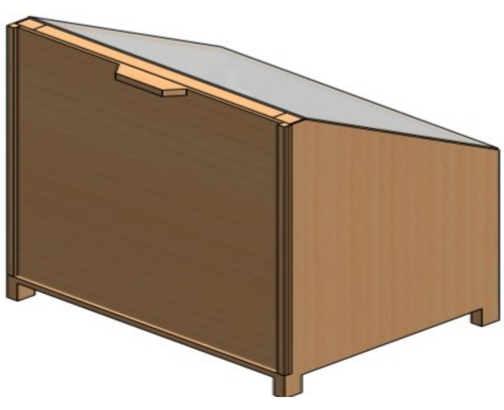

Figure 1: Isometric View of the Solar Dryer

Figure 2: Constructed Solar Dryer

2.6 Operational Procedure

The process of dehydration consists of removal of moisture from the seeds by heat, usually in the presence of a controlled flow of air. First of all the solar dryer is placed directly in the sun facing south in order to get the maximum solar energy. Initially the seeds are prepared and placed on flat gauze and put into the dryer. The solar rays enter the cabinet through the cover material. On reaching the solar collector or the tray surface, they are converted into heat energy raising the temperature inside. The heat energy is transferred to the seeds to be dried. The heated seeds give out water vapor and dries up. Gradually the heated moist air goes up and lives the drying chamber through the air outlet at the high end of the drier. As a result of a natural and conventional process, dry air will enter the drying chamber through the air inlet that is situated at the lower end of the drying chamber. The efficiency of the solar dryer is influenced by relative humidity in the air, the moisture content of the materials to be dried, their amount and thickness. The solar radiation intensity on the materials varies with seasons, time of the day and length of exposure. Ambient air temperature and wind speed are important factors that were put into considerations.

III. RESULTS AND DISCUSSION

The solar seed dryer was tested under no-load and load conditions. From the results obtained during no-load test, it was quite clear that the average temperature of the heated air inside the solar dryer which was higher than the average ambient temperature. The results further indicated that the solar seed dryer can raise the ambient temperature to a higher value for effective drying. The higher value of drying temperature of the dryer is due to the solar collector and the orientation of the collector surface to the south. During the load tests, the solar dryer was tested with maize seeds samples. The results obtained are shown in Table 1 –Table 3. As shown in Figure 3, improved temperature was achieved with the solar dryer for day 1 as there was an increase of temperature throughout against the ambient temperature values obtained. Also, same results were obtained in day 2 and day 3 as shown in Figure 4-Figure 5. The improved solar temperature readings were as a result of good construction resulting from good materials selection.However, the expected temperature of the solar dryer (44°C) was not achieved because of weather conditions and cloud cover. It was observed that large quantity of moisture content was removed throughout the three days. Nevertheless, it was highest in day one, and least in day 2 as shown in Figure 6. This is because on the first day, the skin of the maize was soft and it was easy for evaporation to take place. As the maize dried, the skin became harder and rate of evaporation reduced.

T_S = Solar Chamber Temperature

T_A = Ambient Temperature

M_1 = Initial mass of Maize seed before drying

M_2 = Final mass of Maize seed before drying

$\%M_C$ = Percentage moisture content

The percentage moisture content was determined as follow;

$$\%M_c = \frac{M_1 - M_2}{M_1}$$

where,

$M_1 - M_2$ = Loss in mass of maize

Table 1: Results of Solar Maize Seed Dryer for Day One (1)

Time	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
T_S (°C)	33.45	35.67	39.00	40.03	43.00	42.55	42.98	42.15	33.45
T_A(°C)	29.00	30.00	34.00	35.34	35.70	32.00	34.60	34.02	33.00
M(kg)	M_1 =12.00								M_2 =11.00
	8.33%								

Table 2: Results of Solar Maize Seed Dryer for Day Two (2)

Time	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
T_S (°C)	34.55	34.53	35.45	37.88	38.80	39.15	38.50	36.89	36.85
T_A(°C)	29.01	30.65	31.15	33.95	34.45	35.30	34.75	34.01	32.05
M(kg)	M_1 =10.60								M_2 = 9.80
	7.55%								

Table 3: Results of Solar Maize Seed Dryer for Day Two (3)

Time	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
T_S (°C)	34.05	34.99	36.45	38.23	39.45	40.11	38.44	37.89	37.00
T_A(°C)	29.85	30.45	32.15	34.45	35.00	36.12	34.55	33.65	32.56
M(kg)	M_1 =11.00								M_2 = 10.60
	3.64%								

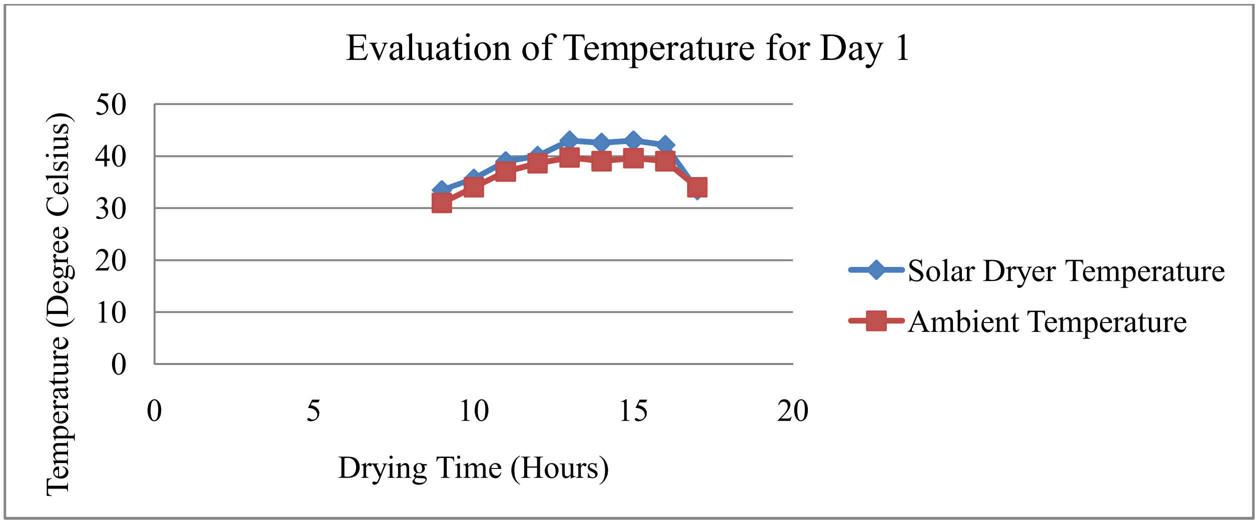

Figure 3: Graph of Temperature against Drying Time for Day 1

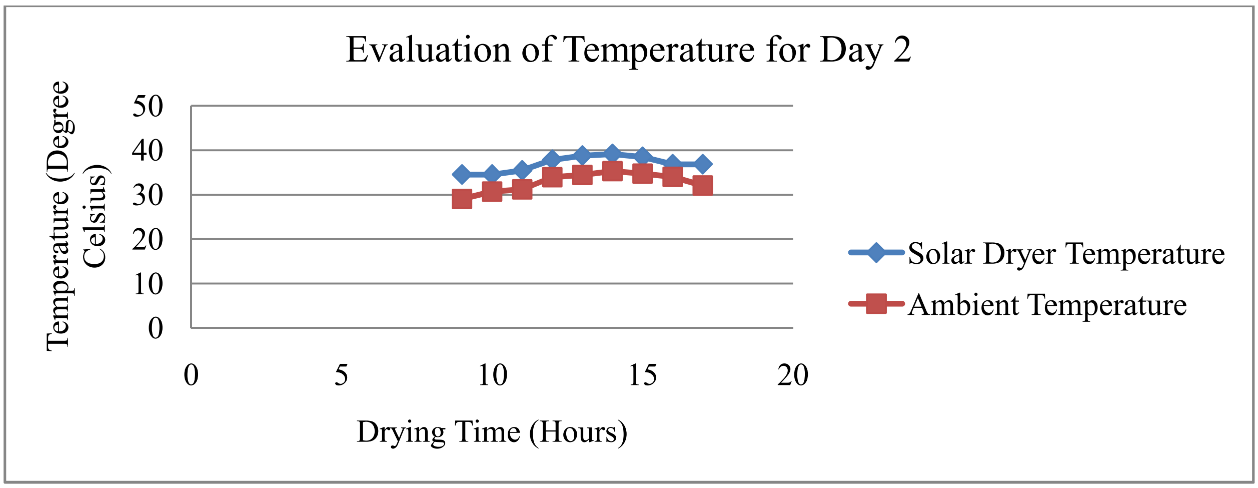

Figure 4: Graph of Temperature against Drying Time for Day 2

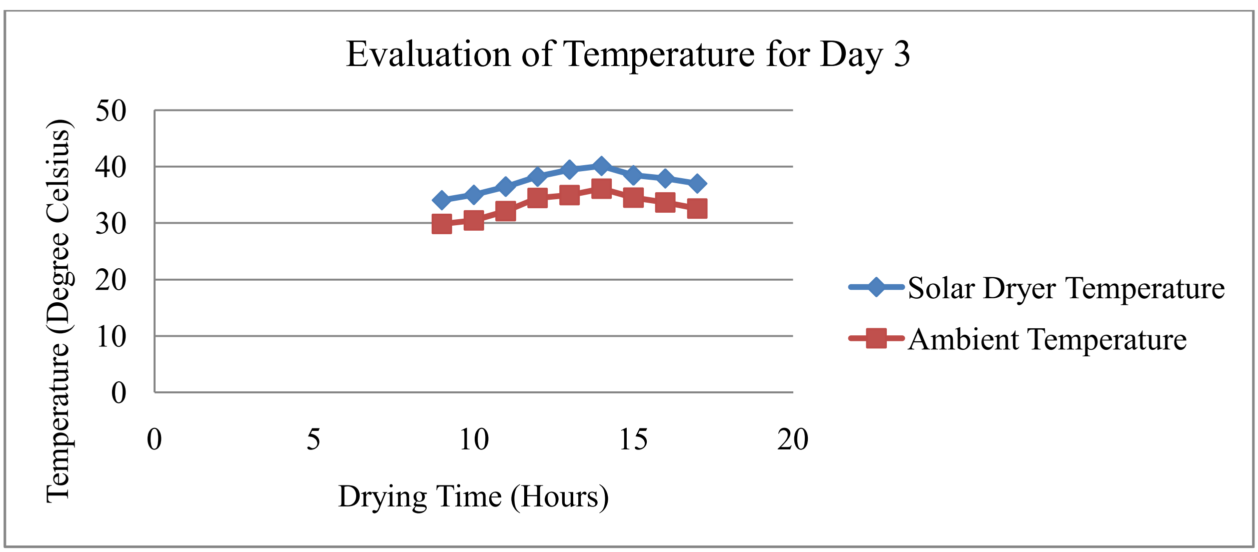

Figure 5: Graph of Temperature against Drying Time for Day 3

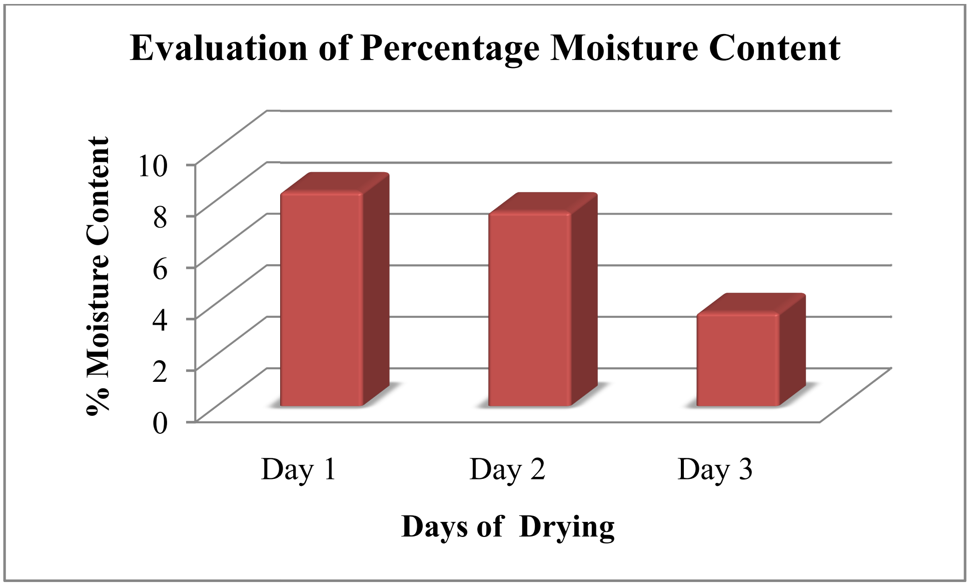

Figure 6: Bar Chart showing Evaluation of Percentage Moisture Content

IV. CONCLUSION

In this research work, a solar dryer was successfully designed and fabricated. From the results of the test carried out, the solar dryer can raise the ambient air temperature to a considerably high value for increasing the drying rate of maize seeds. It required 24 hours split within three days for a successful drying of the maize seeds. Also, the product inside the dryer requires lesser frequent attention compared to those drying in the open sun. Besides, there was a notable decreased in the percentage moisture content throughout the period of experimentation. The dryer is very easy to operate and with the results obtained with maize seeds, the solar dryers can be used to dry various types of crops including vegetables.

REFERENCES

[1] Akinbami, J.F.K., "Renewable Energy Resources and Technologies in Nigeria: Present Situation, Future Prospects and Policy Framework", Migration and Adaptation Strategies for Global Changes (6): pp. 155 – 181, 2001.

[2] Ebunilo, P.O., Aliu, S.A. and Orhorhoro, E.K., "Performance Study of a Biogas Pilot Plant using Domestic Wastes from Benin Metropolis", International Journal of Thermal & Environmental Engineering, volume 10, No 2, pp.135-141, 2015

[3] The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD). (2011) REDD+ Strategy Programme.

[4] Adegbulugbe, A.O., "Bioenergy for Development – Technical and Environmental Dimensions". Environmental and Energy. Series No 13, 1994

[5] Adegoke, C.O., "A Preliminary Investigation of Sawdust as High Grade Solid Fuel. Nigerian Journal of Renewable Energy.Vol. 9. pp. 103, 1999

[6] Tunde, O., Titilayo, A., Kunle, A., Femi, O., Adelana, A., "Energy Crisis in Nigeria: Need for Renewable Energy Mix". American Journal of Electrical and Electronic Engineering, Vol. 4, No. 1, 1-8, 2016

[7] Simonyan K.J. and Fasina O., "Biomass resources and bioenergy potentials in Nigeria". Africa Journal of Agricultural research, Vol. 8(40), pp. 4975-4989, 2013

[8] Ebunilo, P.O., Orhorhoro, E.K.,Chukwudi, C.M., andEssienubong, I.A., "Performance Evaluation of Biomass Briquette from Elephant and Spear grass in Benin City, Edo State, Nigeria", European Journal of Engineering Research and Science, Vol. 1, No. 1, pp. 15-17, July 2016

[9] Energy Commission of Nigeria, Potential for renewable energy application in Nigeria, pp. 1-2, July 1997

[10] Orhorhoro, E.K., Okonkwo, M.C., Oghoghorie, O., and Onogbotsere, M.E., Design and Fabrication of an Improved Low Cost Biomass Briquetting Machine Suitable for use in Nigeria, International Journal of Engineering Technology and Sciences, Vol.8 (1), 2017

[11] Gbaha, P., Yobouet, H., Kouassi, J., Kamenan, B., and Toure, S., "Experimental investigation of a solar dryer with natural convective heat flow", Journal of Renewable Energy, 32:1817-1829, 2007

[12] Exell, R.H.B.,"Basic Design Theory for simple solar rice Dryer", Renewable Energy Review Journal, pp.1- 14, 1980

[13] Anon, R.How to Build a Solar Crop Dryer. Santa Fe, USA: New Mexico Solar Energy Association. pp10., 1978