Journal of Engineering and Applied Science *Volume 4, June 2012*

DESIGN, CONSTRUCTION AND EVALUATION OF A SMALL SCALE SOLAR DRYER

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ABSTRACT
The solar drying system utilizes solar energy to heat up air and to dry any food substance loaded, which is beneficial in reducing wastage of agricultural product and helps in preservation of agricultural product. Based on the limitations of the natural sun drying e.g. exposure to direct sunlight, liability to pests and rodents lack of proper monitoring, and the escalated cost of the mechanical dryer, a solar is therefore developed to cater for this limitation. This project presents the design and construction of a domestic passive solar dryer.The dryer is composed of solar collector (air heater) and a solar drying chamber constraining rack of three cloth (net) trays both being integrated together. The air allowed in through air inlet is heated up in the solar collector and channeled through the drying chamber where it is utilized in drying. The design was based on the geographical location which is Abeokuta and meteorological data were obtained for proper design specification. The dimensions of the dryer is 94cm x 45cm x 101cm / 20cm (length x width x height). Locally available material were used for the construction, chiefly comprising of wood (gmelina), glass, aluminum metal sheet, copper and net cloth for the trays. The optimum temperature of the dryer is 50.50^{O}C with a corresponding ambient temperature of 34.50^{o} C. The moisture content removal of 43.2% and 40.6% in maize and plantain respectively using the solar dryer was achieved as against 28.2% and 27.89% in maize and plantain using the sun drying method and indication 15.0% and 12.71% difference respectively, the rapid rate of drying in the dryer reveals its ability to dry food items reasonable rapidly to a safe moisture.
Keywords: *Solar dryer, Moisture loss, Design and Construction, Maize and Plantain*

INTRODUCTION
Crop drying is the most energy consuming process in all processes on the farm. The purpose of drying is to remove moisture from the agricultural produce so that it can be processed safely and stored for increased periods of time. Crops are also dried before storage or, during storage, by forced circulation of air, to prevent spontaneous combustion by inhibiting fermentation. It is estimated that 20% of the world's grain production is lost after harvest because of inefficient handling and poor implementation of post-harvest technology, says Hartmans (1991). Grains and seeds are normally harvested at a moisture level between 18% and 40% depending on the nature of crop. These must be dried to a level of 7% to 11% depending on application and market need. Once a cereal crop is harvested, it may have to be stored for a period of time before it can be marketed or used as feed. The length of time a cereal can be safely stored will depend on the condition it was harvested and the type of storage facility being utilized. Grains stored at low temperature and moisture contents can be kept in storage for longer period of time before its quality will deteriorate. Some of the

cereals which are normally stored includes maize, rice, beans. Osagieand Eka (1998). Solar drying may be classified into direct and indirect solar dryer. In direct solar dryers the air heater contains the grains and solar energy which passes through a transparent cover and is absorbed by the grains. Essentially, the heat required for drying is provided by radiation to the upper layers and subsequent conduction into the grain bed. However, in indirect dryers, solar energy is collected in a separate solar collector (air heater) and the heated air then passes through the grain bed, while in the mixed-mode type of dryer, the heated air from a separate solar collector is passed through a grain bed, and at the same time, the drying cabinet absorbs solar energy directly through the transparent walls or the roof.

The objective of this study is to develop a mixed-mode solar dryer in which the grains are dried simultaneously by both direct radiation through the transparent walls and roof of the cabinet and by the heated air from the solar collector, as described by (Leon, et al 2002). The problems of low and medium scale processor could be alleviated, if the solar dryer is design and constructed with the consideration of overcoming the limitations of direct and indirect type of solar dryer. So therefore, this work will be based on the importance of a mixed mode solar dryer which is reliable and economically. The objectives of the work is to design and construct a mixed mode solar dryer using locally available materials and to evaluate the performance of the solar dryer.

MATERIALS AND METHODOLGY

Factors considered in selecting the engineering materials for the fabrication of the equipment were:

i. Cost of the fabrication.
ii. Mechanical properties of materials (e.g. stress, creep, fatigue etc).
iii. Corrosion resistance.
iv. Ease of fabrication (e.g. forming, nailing, bending, cutting etc)
v. Service requirement.

Considerations were also given to the most economical materials that satisfy both process and mechanical requirements, over the working life of the solar dryer, allowing for easy loosening, maintenance and replacement. Finally the selected materials to be used were ensured of having sufficient strength and easily worked with.

METHOD

Construction of the mixed-mode solar dryer

The materials used for the construction of the mixed-mode solar dryer are cheap and easily obtainable in the local market. The solar dryer consists of the solar collector (air heater), the drying cabinet and drying trays.

Solar Dryer Components

Drying Chamber: The drying chambers is a highly polished plywood box held in place by angle iron, the material has been chosen since wood is a poor conductor of heat and its smooth surface finish, heat loss by radiation is minimized.

Cover plate: This is a transparent sheet used to cover the absorber, thereby preventing dust and rain from coming in contact with the absorber, it also retards heat from escaping, common materials used for cover plates is a glass.

Absorber plate: This is a metal painted black and placed below the cover to absorb the incident solar radiation transmitted by cover, thereby heating the air between it and the cover, here aluminum is chosen because of its quick response in the absorption of solar-radiation.

Insulation: This is used to minimize heat loss from the system, it is under the absorber plate, the insulator must be able to withstand stagnation temperature, it should be fire resistant and not subject to out-going gassing and should not be damageable by moisture or insect.

The Orientation of the Solar Collector:

The flat-plate solar collector is always tilted and oriented in such a way that it receives maximum solar radiation during the desired season of used. The best stationary orientation is due South in the northern hemisphere and due north in Southern hemisphere. Therefore, solar collector in this work is oriented facing south and tilted at 17.11^0 to the horizontal. This is approximately 10^0 more than the local geographical latitude (Abeokuta a location in Nigeria, 7.11^0N), which according to Adegoke and Bolaji (2000), is the best recommended orientation for stationary absorbers. This inclination is also to allow easy run off of water and enhance air circulation.

Design Consideration

- **Calculation:** This entails all the mathematical approaches and formula used in obtaining the dimensions.
- **Drawing:** This shows the pictorials of the extended machine being designed.

Fabrication: This is the final structure developed from combination of the calculations and drawing

Fig 1: Design of Solar Dryer (Sectional view).

Design Calculations

1. **Angle of Tilt (β) of Solar Collector/Air Heater.**

The angle of tilt (β) of the solar collector is given by the formula below:

$\beta = 100 + \text{at } \Phi$ (Alamu, 2010)

where, lat Φ is the attitude of the collector location,

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2. **Insolation on the Collector Surface Area.**

A researcher obtained the value of insolation for Abeokuta i.e. average daily radiation H on horizontal surface as H = 978.69W/m^2 (Olaleye 1996) and average effective ration of solar energy on tilted surface to that on the horizontal surface R as; R = 1.0035 (Olaleye 1996)

3. **Determination of Collector Area and Dimension.**

The air gap height was taken as 5.6cm – 0.056m and the width of the collection assumed to be 45cm – 0.45m.
Thus, volumetric flow rate of air V'a =Va x 0.056 x 0.38
Va = 0.15 x 0.056 x 0.38 = 3.19 x 10-3m3/s
Thus mass flow rate of air: Ma = vapa (dorf, 1989)
Density of air is taken as 1.2252kg/m3 at S.T.P.

4. **Determination of the Base Insulator Thickness for the Collector**

For the design, the thickness of the insulator was taken as 7cm. The side of the collector was made of wood, the loss through the side of the collector will be considered negligible.

5. **Dryer efficiency:** This is given as,

Efficiency (%) = work output/work input x 100/1
(Ezekoye, 2006)

Where (work output) is the final mass of the crop after drying and (work input) is the initial mass of the crop before drying.

6. **Moisture Content (M.C.):** The moisture content is given as:

M.C =$(M_1-M_2)/M_1$ … (Ezekoye, 2006)

Where M_1 = mass of sample before drying and M_2 = mass of sample after drying.

7. **Moisture loss ML:** The moisture Loss is given as

= (M_1-M_2) (g)…. (Ezekoye, 2006)

Where M_1 is the mass of the sample before drying and M_2 is the mass of the sample after.

8. **Design dimension of the chamber**

Dimensions are in cm
1000cm = 1liter
capacity:

(L * W * B)/ 1000

RESULTS AND DISCUSSION

Results

1. **Angle of Tilt (β) of Solar Collector/Air Heater.**

The angle of tilt (β) of the solar collector is given by the formula below:

$\beta = 10^o + \text{at } \Phi$ (Alamu, 2010)

where lat Φ is the attitude of the collector location, the latitude of Abeokuta where the dryer was designed is latitude 7.11^0N.

Hence, the suitable value of β use for the collector:

$\beta = 10^0 + 7.11^0 = 17.11^0$.

2. **Insolation on the Collector Surface Area.**

A research obtained the value of insolation for Abeokuta i.e. average daily radiation H on horizontal surface as H = 978.69W/m2 (Olaleye 1996) and average effective ration=of solar energy on tilted surface to that on the horizontal surface R as; R = 1.0035 (Olaleye 1996).

Thus, insolation on the collector surface was obtained as

1c = HT = HR = 978.69 x 1.0035 = 982.11W/m2 (GEDA-Gujarat Energy Development Agency, 2003).

3. **Determination of Collector Area and Dimension.**

The air gap height was taken as 5.6cm – 0.056m and the width of the collection assumed to be 45cm – 0.45m.

Thus, volumetric flow rate of air V'a =Va x 0.056 x 0.38

Va = 0.15 x 0.056 x 0.38 = 3.19 x 10-3m3/s

Thus, mass flow rate of air: Ma = vapa (Dorf, 1989)

Density of air is taken as 1.2252kg/m3 at S.T.P.

Ma = 3.19 x 10.3 x 1.2252 = 3.91 x 10.3kg/s

Therefore, area of the collector AC

AC = (3.91 x 10-3 x 1000 x 30)/(0.5 c 982.11) = 0.239m^2

The length of the solar collector (L) was taken as;

L = Ac/B = 0.3537/0.45 = 0.53m. Thus, the length of the solar collector was taken approximately as 0.6m

Therefore, collector area was taken as (0.45 x 0.53) 2 = 0.239m^2

4. **Determination of the Base Insulator Thickness for the Collector**

For the design, the thickness of the insulator was taken as 7cm. The side of the collector was made of wood, the loss through the side of the collector will be considered negligible.

Where M_1 is the mass of the sample before drying and M_2 is the mass of the sample after.

5. **Design dimension of the chamber**

Dimensions are in cm

1000cm = 1liter

Capacity: (45 * 45 * 50)/ 1000 = 101.25 liters

Mass of water removed = (560-318)g =242g

% of total moisture content loss in maize (On wet basis) = $\frac{\text{initial mass – final mass}}{\text{Initial mass}} \times \frac{100}{1}$

$= \frac{560-318}{560} \times \frac{100}{1} = 43.2\%$

% efficiency of the dryer with maize = work output/work input x 100/1

$= \frac{318}{560} \times \frac{100}{1} = 56.78\%$ per day

(for 9hrs during the day light)

Mass of water removed = (276- 163.8)g

=112.2g

% of total moisture content loss in plantain (On wet basis) = $\frac{\text{initial mass – final mass}}{\text{Initial mass}} \times \frac{100}{1}$

$= \frac{276-163.2}{276} \times \frac{100}{1} = 40.6\%$

% efficiency of the dryer with plantain = work output/work input x 100/1

$= \frac{163.2}{276} \times 100 = 59.13\%$ per day

(for 9hrs during the day light)

Table 3 and 4 shows the variation in the moisture content removed in the case of both solar drying and sun drying and Table 4.5 shows evaluated parameter of the solar dryer obtained.

DISCUSSION

Fig.2 shows a typical day results of the hourly variation of the temperatures in the solar collector and the drying cabinet compared to the ambient temperature. The dryer is hottest about mid-day when the sun is usually overhead. The temperatures inside the dryer and the solar collector were much higher than the ambient temperature during most hours of the daylight. The temperature rises inside drying cabinet for about three hours immediately after 12.00h (noon). This indicates prospect for better performance than open-air sun drying. Fig. 2 shows the diurnal variation of the relative humidity of the ambient air and drying chamber.

Comparison of this figure with Fig.1 shows that the drying processes were enhanced by the heated air at very low humidity Fig. 3 shows the drying curve for maize and Plantain slices in the solar dryer. It was observed that the drying rate increased due to increase in temperatures between 10.00h and 14.00h but decreased thereafter, which shows the earlier and faster removal of moisture from the dried item. The total moisture content removed are 43.2%and 40.6% in maize and plantain respectively using the solar dryer was achieved against 28.2% and 27.89% in maize and plantain respectively using the sun drying method. The efficiency of the mixed-mode solar dryer during the test period was found to be 56.78% and 59.13% in maize and plantain respectively.

CONCLUSION

From the test carried out, the following conclusions were made.The solar dryer can raise the ambient air temperature to a considerable high value for increasing the drying rate of agricultural crops. The product inside the dryer requires less attentions, like attack of the product by rain or pest (both human and animals), compared with those in the open sun drying. Although the dryer was used to dry maize and plantain, it can be used to dry other crops like yams, cassava etc. There is ease in monitoring when compared to the natural sun drying technique. The capital cost involved in the construction of a solar dryer is much lower to that of a mechanical dryer. The collector and dryer efficiencies are very reasonable.

RECOMMENDATION

The performance of existing solar food dryers can still be improved upon especially in the aspect of reducing the drying time, and probably storage of heat energy within the system by increasing the size of the solar collector. Also, meteorological data should be readily available to users of solar products to ensure maximum efficiency and effectiveness of the system. Such information will probably guide a local farmer on when to dry his agricultural produce and when not to dry them.

TABLE 1: Hourly Moisture Loss and Mass of the maize

Time	Mass of maize(g)	Moisture loss (g)	% Moisture loss	Total Moisture Loss (%)
9.00	560	-		58
10.00	547	13	2.3	55.7
11.00	528	19	3.4	52.3
12.00	503	25	4.5	47.8
13.00	474	29	5.2	42.6
14.00	436	38	6.8	35.8
15.00	399	37	6.6	29.2
16.00	365	34	6.0	23.2
17.00	338	27	4.8	18.4
18.00	318	20	3.6	14.8

TABLE 2: Hourly Moisture Loss and mass of the Plantain

Time	Mass of plantain(g)	Moisture loss (g)	% Moisture Loss	Total moisture loss (%)
9.00	276	-		72
10.00	271.9	4.1	1.5	70.5
11.00	263.5	8.4	3	67.5
12.00	252.8	10.7	3.9	63.6
13.00	238.6	14.2	5.2	58.4
14.00	222.9	15.7	5.7	52.7
15.00	205.4	17.5	6.3	46.4
16.00	188.9	16.5	6	40.4
18.00	175	13.9	5	35.4
18.00	163.8	11.2	4.1	31.3

TABLE 3: Solar drying

MAIZE		PLANTAIN	
Initial Mass (g)	Final Mass (g)	Initial Mass (g)	Final Mass (g)
560	318	276	163.8

Total % moisture loss 43.2%	Total % moisture loss 40.6%

TABLE 4: Sun-drying

MAIZE		PLANTAIN	
Initial Mass (g)	Final Mass (g)	Initial Mass (g)	Final Mass (g)
560	402	276	199

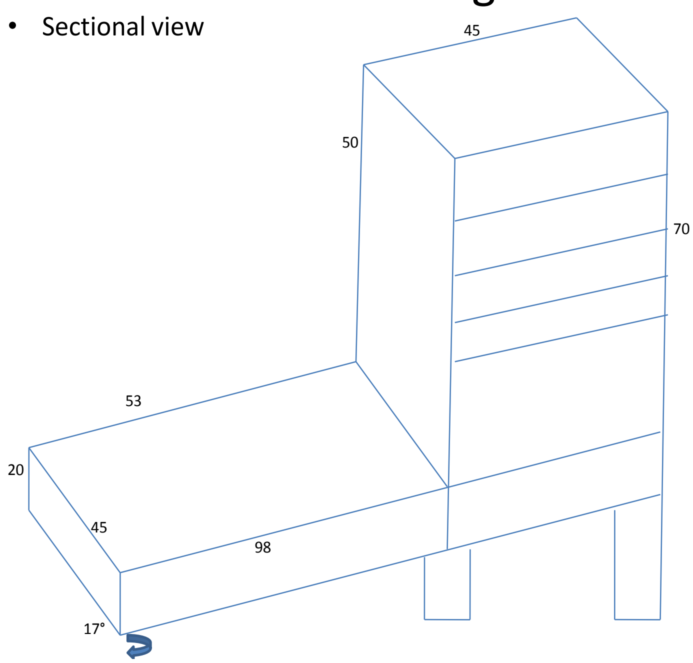
Total % moisture loss 28.2%	Total % moisture loss 27.89%

Table 5: **Evaluated Parameters of the Dryer**

Parameter	**Values Obtain**
Insolation on the Collector Surface	982.11 W/m^2
Total moisture content loss (on wet basis) For maize For plantain	 43.2% 40.6%
Dryer capacity	9kg (but depends on the volume and nature of the product)
Dryer efficiency With maize With plantain	 56.78% per day for 9hrs during 59.13% per day the day light
Volume of Dryer chamber r (V)	101.25liters
Collector Area (A)	0.238m^2
Collector Efficiency ηc	37.9% (average)
Collector slope (β)	17.11°

The Design

- Sectional view



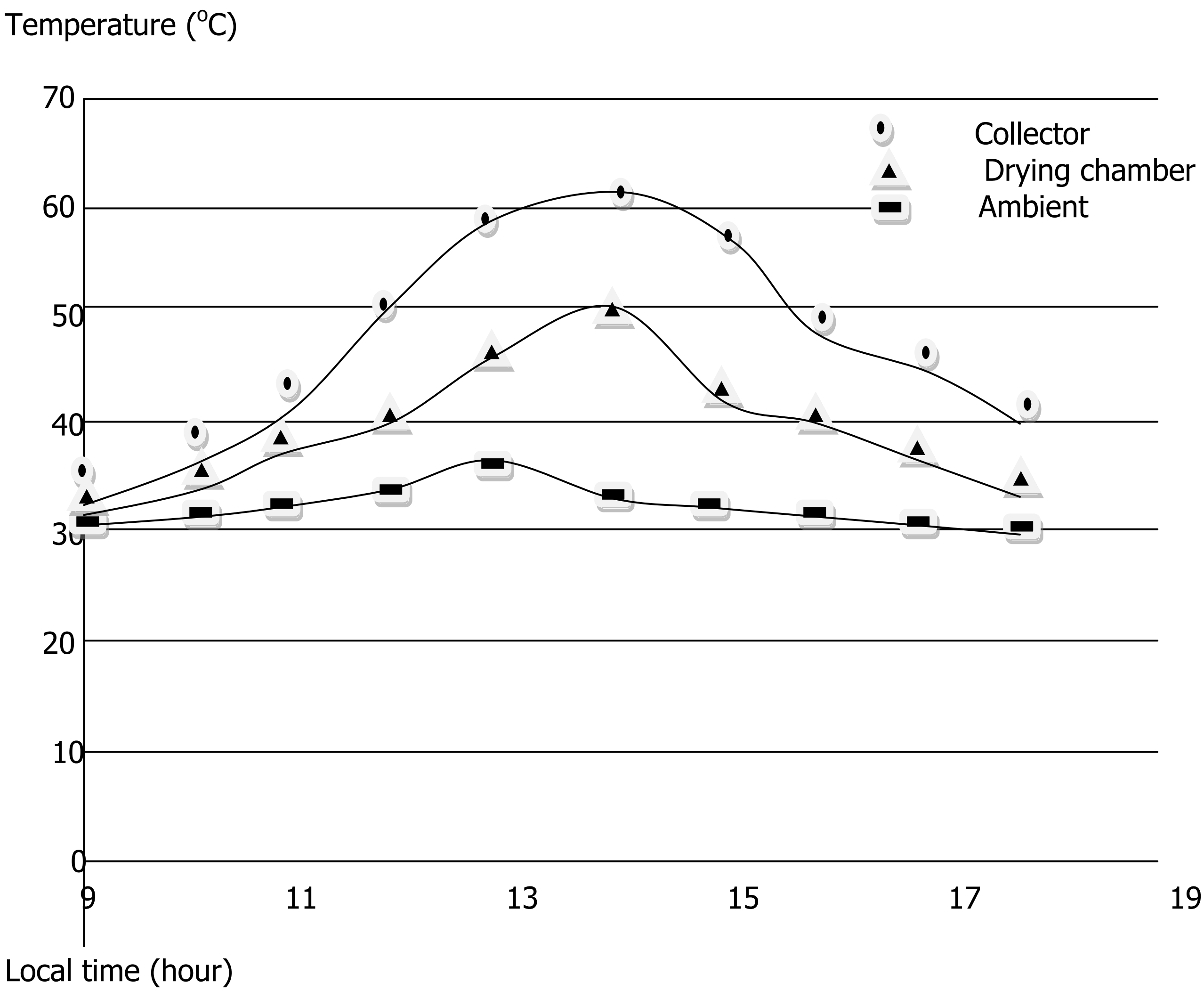


Fig. 2: A typical day results of the diurnal variation of temperatures in the solar dryer.

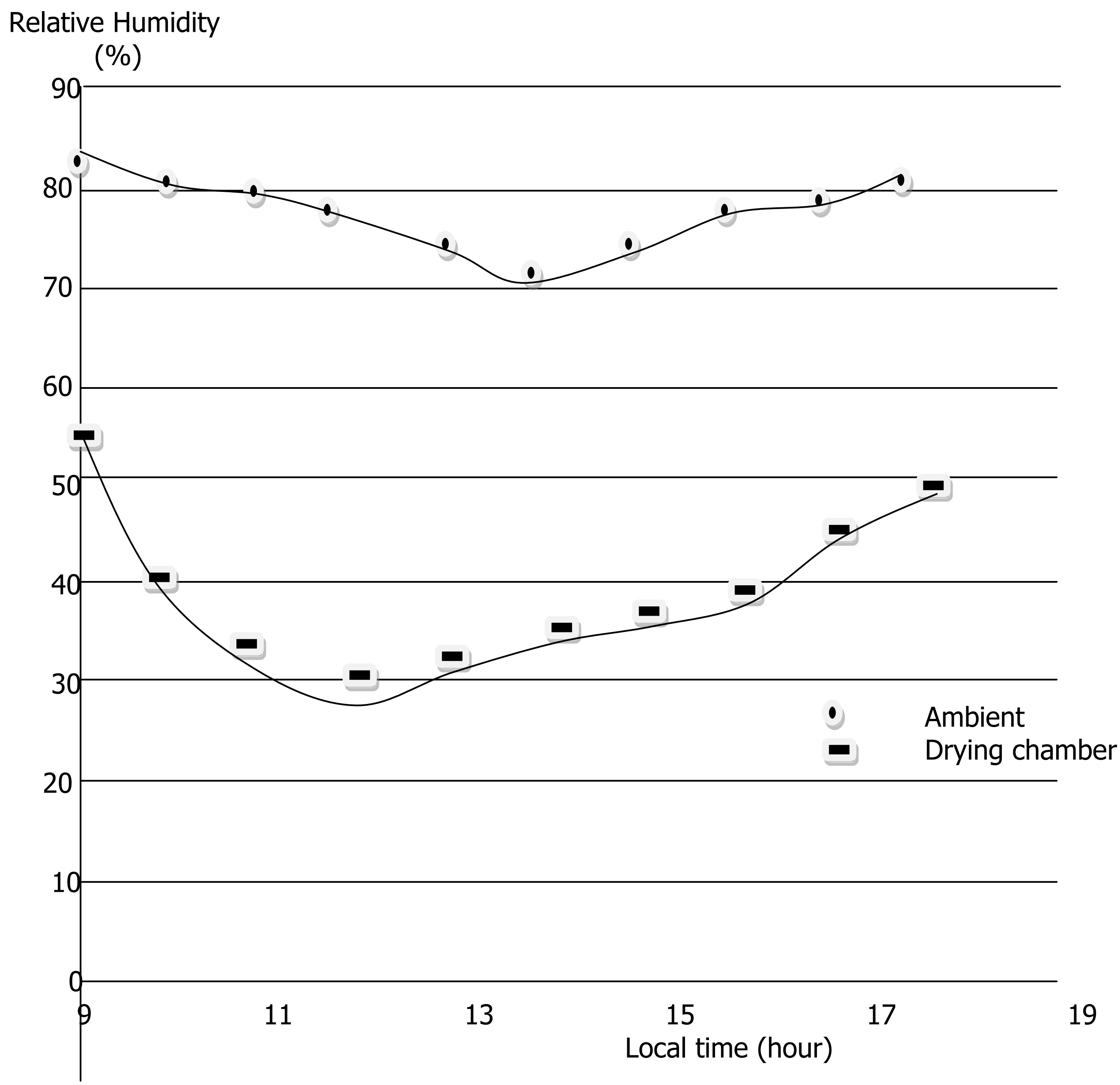


Fig. 3: A typical day results of the diurnal variation of relative humidity in the dryer.

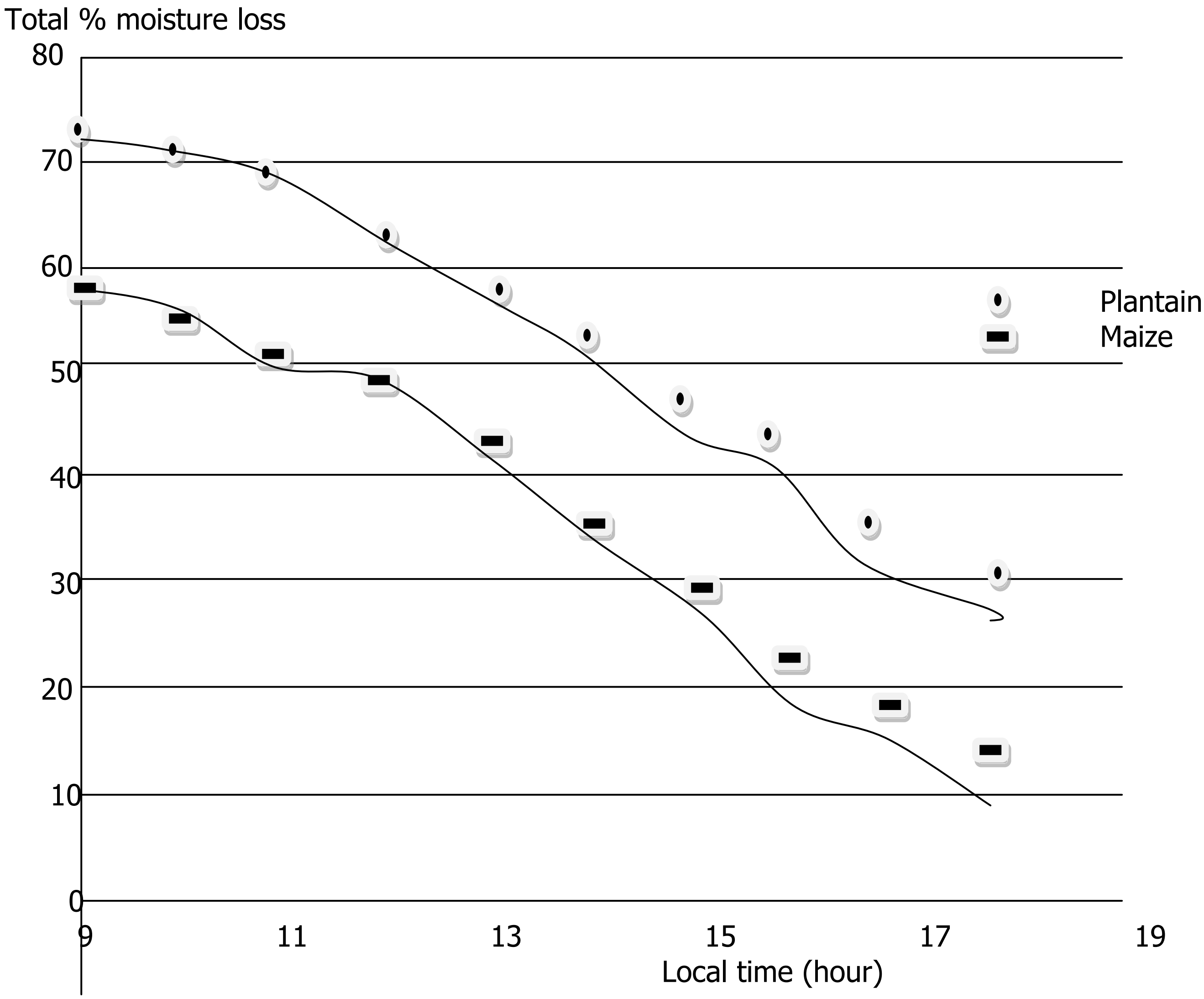


Fig. 4: Drying curve for maize and plantain slices

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