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Full Length Research Paper

Utilization of greenhouse effect for solar drying of cassava chips

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An indirect passive solar dryer was designed, constructed and tested. The dryer was designed to accommodate a total quantity of 45 kg and was tested by carrying out three experiments with fresh cassava chips of approximate sizes of 2.5, 3.0 and 3.5 cm. The highest temperature recorded during the experiments was 60.5°C. The average result shows that the 3.0 cm chips inside the drying chamber were dried from 65% (187% dry basis) to 10% (11% db) moisture content in 4 days, while the samples outside the chamber were dried to 11% (13% dry basis) in 6 days. This result shows that over thirty percent saving in drying time was achieved in the dryer compared to the open sun drying. The calculated drying efficiency and the Pick-up efficiency of the dryer are 31 and 58% respectively. The organoleptic quality test of the dried cassava chips showed that samples in the dryer retained their white colour, thus, indicating no mould growth.

Key words: Cassava, chips, dryer, solar-drying, storage.

INTRODUCTION

Cassava (*Manihot esculenta Crantz*) is a highly valued agricultural produce. It provides about 40% of all dietary intakes of many developing countries of Africa, Latin America and Asia (IITA, 1990). The roots contain about 30 – 40% dry matter of which starch, sugar and vitamin C are the predominant components used in the formulation of animal feeds and industrial raw materials. It is grown mainly in the lowland of tropical regions of the equatorial belt bonded by latitude 30°N and 30°S and is restricted to zones less than 2000 m above sea level, receiving annual rainfall of 200 - 2000 mm (RMRDC, 2004). Nigeria is the World's highest producer of cassava accounting for over 70% of the total production in West Africa and about 40% of the global annual production (Nweke, 1996).

Cassava chips are pieces of dried irregular slices of cassava which vary in sizes but not exceeding 5 - 6 cm in length (Cortis, 1980). Flour is the most widely used form in which dried cassava roots can be marketed and most exporting countries produced them. Despite the economic viability of cassava roots, the local farmers are faced with high loses due to poor storage (IITA, 1990). This is because the roots are perishable after harvest and therefore need to be dried or consumed immediately. The essential steps of processing cassava tubers include: peeling, washing, cutting, slicing, grating, drying, grinding and milling (Asiedu, 1989). Hence, drying is an important operation in the cassava processing and utilization cycle. Although, various storage and processing techniques are employed by the local farmers traditionally, this project was carried out in order to develop and construct a solar dryer that can be used to dry cassava chips.

METHODOLOGY

The methodology adopted in this study consists of Conceptualization of the dryer configuration, Design of the conceptualized dryer, Construction of the designed dryer and Evaluation of the dryer.

Based on the quantity of cassava required to be dried per batch the configurations of the dryer includes a rectangular drying chamber with an inlet and outlet so as to facilitate the entry of ambient drier air from one end, and the exit of warmer moist air on the other end. The basis of the design/dimension of the conceptualized dryer is for the drying chamber to accommodate 45 kg of fresh cassava chips. The sizes of other components of the dryer are designed to conform to the size of the chamber. Kaduna town is at about latitude 10°N, that is, it is at the Northern hemisphere. This implies that a collector situated in the northern hemisphere and is facing South will receive the most insulation. In Northern Nigeria, the dry season spans from December to February, so the mid point of January (That is, 15th) will be taken as n = 15 and was used to cal-

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culate the angle of declination, Q from equation (1) (Holland, 1978).

$$Q = 23.45 \sin [0.9863(284+n)] \quad (1)$$

This implies that for a surface (solar collector) to be perpendicular to insolation at this time, it must face south at a slope of 19.26° from the horizontal. In this work a slope angle of 19° is used and the area of the collector is 1.5 m^2 = 1.0 m wide x 1.5 m long. The constructed solar dryer consists of the followings:

(i) The Frame which consists of a 30 mm square angle iron with a clear space of 50 cm above the ground. Its internal volume is 100 cm long x 10 cm wide x 120 cm high.
(ii) The Absorber Plate which consists of 1.5 mm mild steel sheet metal inclined at an angle of 19° and painted black with black paint. The bottom and sides of the absorber plate are lined with 25 mm insulating particle board. To preserve the collector from damage due to rain fall, it is made detachable so that at the end of drying period, the whole collector can be detached and kept safely for further use.
(iii) The Transparent Cover is a 5 mm thick clear transparent glass sheet 15 cm above the absorber plate.
(iv) Three Drying Trays are provided in the drying chamber at different levels from the floor of the chamber. Each tray has a floor area of 100 cm x 100 cm with a carrying capacity of 15 kg of fresh cassava chips (Rozin, 1997). The tray floor is constructed from 25 mm chrome-plated wire gauge. They slide on 25 mm square angle iron fixed to the walls of the chamber.
(v) A cylindrical chimney of 5 cm diameter and 10 cm high is positioned at the top of the drying chamber for ventilation. Cool air coming in through the aperture is heated up at the absorber plate surface and rises through the drying chamber to the exit opening at the top (chimney).
(vi) A door at the left side of the chamber is provided to give easy and free access to the drying trays.
(vi) Air Inlet Aperture is located at the front of the dryer. It is 15 cm high and 100 cm wide as shown in appendix B.

To evaluate the constructed dryer, fresh harvested cassava tubers were bought from Kawo market in Kaduna North local government area, Kaduna state, Nigeria. The tubers were peeled manually and then chipped into slices of average thickness of about 2.5, 3.0 and 3.5 cm. The drying areas were divided into three trays; top, middle and bottom trays in the chamber. A control sample was placed outside the drying chamber. The chips were then spread on the trays. Throughout the duration of the drying process measurements were taken of ambient temperature, solar collector temperature, relative humidity of the air entering the collector and the drying chamber, air speed, solar radiation, temperature of the drying chamber and weights of samples. The instruments used include: Haenni Solar 118 Delta, Dry bulb and Wet bulb Thermometers, A digital Hand-held Wind Speed Anemometer, Harvard Trip Balance and Wang Weighing Balance.

Moisture content determination

At the beginning of the experiment, the weights of the representative samples were obtained and by using the initial moisture content, the oven dry weights of the representation sample can be obtained, since:

$$M.C\%(db) = \frac{W_w - W_d}{W_d} x100 \quad (2)$$

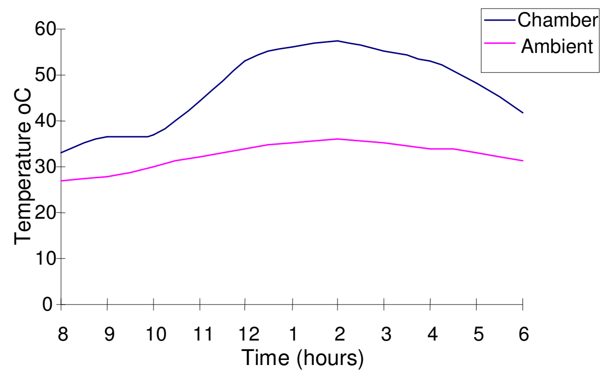

Figure 1. Average temp. variation for experiment 1.

$$W_d = \frac{W_w}{1 + \frac{MC\%}{100}} \quad (3)$$

Where;
W_d = oven dry weight of Sample (g)
W_w= wet weight of sample (g)
M.C= initial moisture content (% db)

During the period of the experiment, daily weights were taken and recorded and the results obtained were shown in appendix B. The calculations of the oven dry weights for each experiment are also shown in appendix B. Since the oven dry weights and the daily weights are known, the moisture content of any of the sample after time t (days) of drying is determined using the equation (4) below:

$$M.C_t\%(db) = \frac{W_w - W_d}{W_d} x100 \quad (4)$$

Where; $M.C_t$ = moisture content after time, t (days).

RESULTS AND DISCUSSION

Three experiments were carried out to test the performance of the designed and constructed dryer. In the first, second and third experiments, cassava chips of average sizes of 2.5, 3.0 and 3.5 cm thickness respectively were used. The average temperature readings for experiments 1, 2 and 3 are shown in appendix A while variation in M.C. (% db) for experiments 1, 2 and 3 are shown in appendix B.

Experiment 1

The average temperature readings for experiment 1 are graphically represented in Figure 1. At sun rise, the chamber and ambient temperatures were 33 and 27°C respectively. These increased to maximum of 57 and 36°C at 2.00 pm. However, at sun set, the temperatures

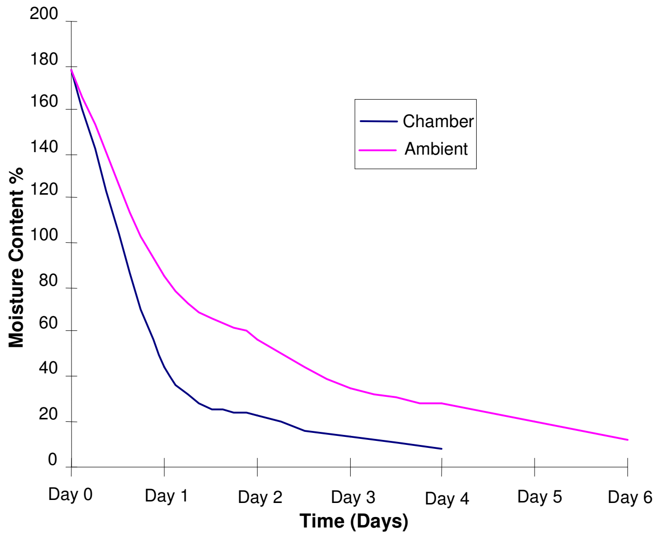

Figure 2. Variation in M.C. (% db) for experiment 1.

reduced to 42 and 31°C respectively. This means that some heat was stored in the dryer even after the sun set for drying to continue during the night. The average moisture content variations of the samples are shown in Figure 2. The result shows that the chips inside the drying chamber were dried from an initial average moisture content of 64% (178% db) to an average of 7% (8% db) in 4 days, while the chips outside the chamber were dried to 11% (12% db) 6 days.

Experiment 2

Average temperature readings for experiment 2 are graphically represented in Figure 3. The highest temperature readings in the chamber and of ambient recorded at 1.00 pm were 55 and 37°C respectively. At sun set, the temperatures are 41°C for chamber and 27°C ambient while at sun rise the temperatures are 35 and 28°C. The average moisture content of samples in the chamber is graphically compared with that of the sample on the control tray as shown in Figure 4. The results showed that the dryer dried cassava chips from 66% (186% db) to 11% (12% db) in 4 days, while it took 6 days for the control sample to reach 13% (15% db) moisture content.

Experiment 3

Average temperature readings for experiment 3 are graphically represented in Figure 5. It was clear that at sun rise the chamber and ambient temperature were 33 and 27°C respectively. These rose to maximum of 60 and35°C at 1.00 pm. However, at sun set, the temperatures reduced to 45 and 28°C. This indicated that the dryer has residual heat even after the sun set and hence

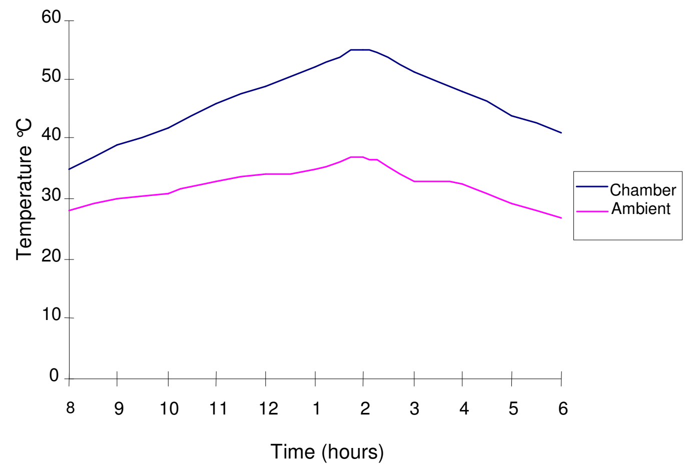

Figure 3. Average temperature variation for experiment 2.

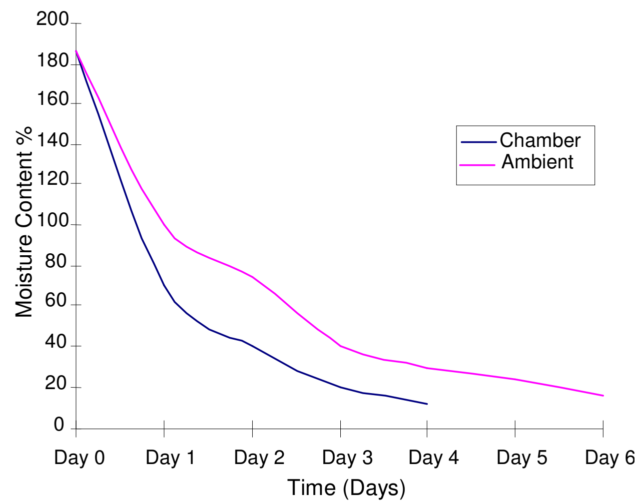

Figure 4. Variation in M.C. (%db) for Experiment 2.

the sun set and hence drying continues. Figure 6 represents the variation in moisture contents. The chips in the dryer were dried from 66% (197% db) to 13% (15% db) in 4 days, while the chips outside the chamber were dried to 11% (12% db) 6 days.

Discussions on moisture content variations for experiments 1, 2 and 3

Comparison of Moisture Content variations for experiments 1, 2 and 3 is graphically produced in Figure 7.

From the figure it could be observed that each curve has a rapidly sloping part and a gradually sloppy part. The rapid nature of the curves at the earlier part of the drying period was due to the surface liquid which exists in the fresh product. The liquid evaporates with as little

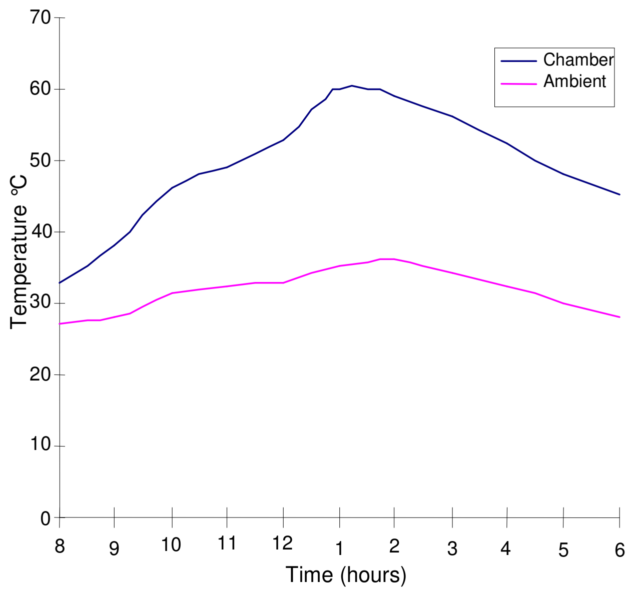

Figure 5. Average temp. variation for experiment 3.

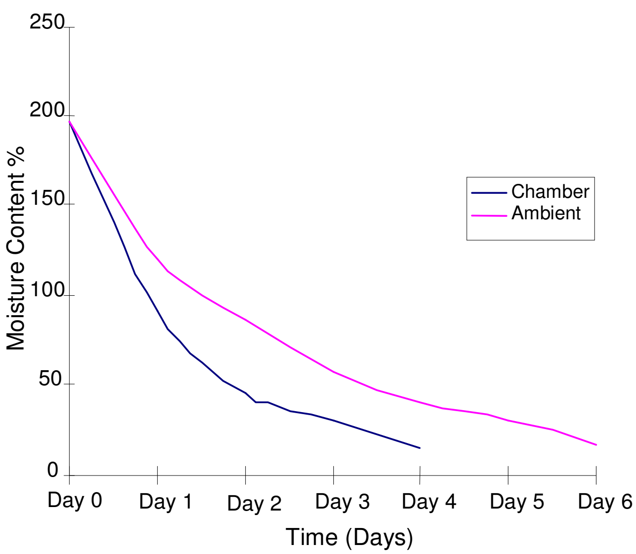

Figure 6. Variation in M.C. (% db) for experiment 3.

energy as possible that the dryer can supply. Thus, the drying preceded in a manner comparable to an open faced body of water, hence the rapid nature of the curve. As the drying continues, the level of moisture reduced considerably and as such, the more moisture is removed the higher the energy is needed to dry further. That is, more energy is needed to remove moisture as the moisture content approaches the equilibrium moisture content. This explains why the graph towards the end of the drying proceeds slowly. Averagely, moisture was reduced from 65% (187% db) to 11% (12% db) in 4 days for an

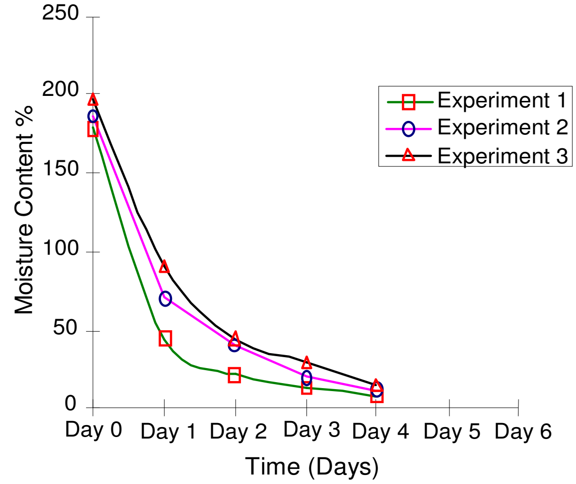

Figure 7. M.C. Variations for Experimentss 1, 2 and 3.

average cassava chip sizes of 3.0 cm.

Determination of dryer efficiencies

System Drying Efficiency (η_c) is the ratio of the energy required to evaporate the moisture to the energy supplied to the dryer. It is a measure of the overall effectiveness of a drying system.

The average daily insulation (I_c) incident on the collector was determined from the data collected during the drying to be 473.36 Wm^{-2}. The latent heat of vaporization (L_v) of water is 2326000 Jkg^{-1} at 40°C [6]. When 45 kg of cassava chips at 65% initial moisture content (wet basis) was dried to 11% moisture content in an average of 4 days, the system drying efficiency of the dryer is calculated using equation (5) (Brenndorfer et al., 1987) as follows:

Thus:

$$\eta_d = \frac{M_w L_v}{I_c A_c t} \quad (5)$$

Weight of moisture (M_w) = 27.72 kg
The dryer area (A_c) = 3.0 m^2
t = 4 days (10 hours daily) = 144000 sec.

Substituting the values in equation (5) yields

$$\eta_d = \frac{27.72 \times 2326000 \times 100}{473.36 \times 3.0 \times 144000} = 31\%$$

Collector Efficiency ($\square_c$) is a measure of how effectively the energy available in the insulation incident upon a collector is transferred to the air flowing through the collector.

The volumetric flow rate (V) of air through an air plenum of 5 cm height and 150 cm length of the air duct and with an average air speed of 7.33 m s^{-1} through the drying chamber is calculated using equation (6) (Brenndorfer et al., 1987) as follows:

$$\eta_c = \frac{V\rho\Delta T C_p}{A_c I_c} \tag{6}$$

V = 0.05 x 1.5 x 7.33 = 0.55 $m^3 s^{-1}$, ΔT = (60 – 36) = 24°C. ρ = 1.23 kg m^{-3}, C_p = 1004 J kg^{-1} °C^{-1}, A_c = 3 m^2, I_c = 473.36 W m^{-2}

Substituting the above values into equation (6) yields:

$$\eta_c = \frac{0.55\times 1.23\times 24\times 1004\times 100}{3.0\times 473.36} = 17\%$$

Pick-up Efficiency (η_p) is the ratio of the moisture 'pick-up' by the air in the drying chamber to the theoretical capacity of the air to absorb moisture. This parameter is useful for evaluating the actual evaporation of moisture from the commodity being dried. It is a direct measure of how efficiently the capacity of heated air to absorb moisture is utilized. This is expressed by the formula as shown in equation (7) (Brenndorfer et al., 1987):

$$\eta_p = \frac{M_o - M_t}{v\rho t(h_{as} - h_i)} \tag{7}$$

h_{as} and h_i are calculated using the psychometric chart. h_i at 60°C and 36% RH is 0.0257 kg kg^{-1}, h_{as} is also found from psychometric chart by following a line of constant humidity from h_i to its intercept with 60°C line and then along the line of constant enthalpy to its intercept with the 100% saturation curve, giving a value of 0.0273 kg kg^{-1}. Substituting the values into equation (8) yields

$$\eta_P = \frac{27.72\times 100}{0.55\times 1.23\times 144000\times(0.0273-0.0257)} = 58\%$$

Conclusion and Recommendation

An indirect passive solar dryer has been designed, fabricated and tested. The field experimental results showed that the performance of the solar dryer was very encouraging when compared to open sun drying method. Over thirty percent saving in drying time was achieved compared with the open sun drying method. The System drying efficiency which is the ratio of the energy required evaporating the moisture to the energy supplied to the dryer, or a measure of the overall effectiveness of the drying system is 31%, while the measure of how effectively the energy available in the insolation incident upon a collector is transferred to the air flowing through the collector is only 17%. This is due to clouds and rains which affected the amount of solar insolation passing through glazing material. However, the measure of how efficiently the capacity of the heated air to absorb moisture in the dryer is 58%. This means that the insulation to heat loses is good.

The problems of insects, mould, fungi and rodent infestation were however, removed since the products were protected. Dirt and dust were also eliminated, thereby producing better quality products. The dryer could also be used to dry products with high, moderate or low moisture contents such as cereal (maize, sorghum etc), melon seeds, fruits and vegetables.

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APPENDIX

Appendix A

Table 1. Average temperature readings for experiment 1(℃).

Time (h)	Chamber (℃)	Ambient (℃)	R/Humidity (%)	Irradiation (W/m²)	Wind speed (Km/h)
8.00	33	27	42	332	10
9.00	36.5	28			
10.00	37	30			
11.00	49	32			
12.00	53	34	37	827	6
1.00	56	36			
2.00	57	36			
3.00	55	36	26	470	2
4.00	53	34			
5.00	48	33			
6.00	42	31	44	69	2

Table 2. Average temperature readings for experiment 2.

Time (h)	Chamber (℃)	Ambient (℃)	R/Humidity (%)	Irradiation (W/m²)	Wind speed (Km/h)
8.00	35	28	48	348	10
9.00	39	30			
10.00	42	31			
11.00	46	33			
12.00	49	34	37	816	6
1.00	52	35			
2.00	55	37			
3.00	51	33	31	497	3
4.00	48	33			
5.00	44	29			
6.00	41	27	50	54	2

Table 3. Average temperature readings for experiment 3.

Time (h)	Chamber (℃)	Ambient (℃)	R/Humidity (%)	Irradiation (W/m²)	Wind speed (Km/h)
8.00	33	27	48	278	11
9.00	38	28			
10.00	46	31			
11.00	49	32			
12.00	53	33	30	764	5
1.00	60	35			
2.00	59	36			
3.00	56	34			
4.00	52	32	39	555	5
5.00	48	30			
6.00	45	28	41	63	3

Appendix B

Daily weight records of representative samples.

Experiment 1 (g)

	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Chamber	322.6	126.4	106.3	98.4	94.1		
Outside	218.0	145.1	123.1	105.9	100.4	93.3	87.8

Experiment 2 (g)

	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Chamber	312.8	186.1	153.3	131.4	120.3		
Outside	253.0	176.9	154.8	124.7	112.3	105.3	101.7

Experiment 3 (g)

	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Chamber	350.7	219.8	167.8	150.4	127.3		
Outside	287.0	212.6	173.9	145.0	130.5	117.9	108.2

Moisture content (oven dry method) of fresh cassava

Experiments	Weight of fresh cassava (g)	Weight of oven dried cassava (g)	Weight of water removed (g)	Moisture content Wet basis (%)	Moisture content dry basis (%)
Experiment 3	350.7	96.63	254.07	197	64
Experiment 1	322.6	78.42	244.18	178	66
Experiment 2	312.8	88.46	224.34	186	66
Average	328.7	87.84	240.86	187	65

Variation in M.C. (% db) of drying material in comparison with control sample.

Experiment 1

	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Chamber	64(178)	31(45)	18(22)	12(13)	7(8)		
Outside	64(178)	46(85)	36(57)	26(35)	22(28)	16(19)	11(12)

Experiment 2

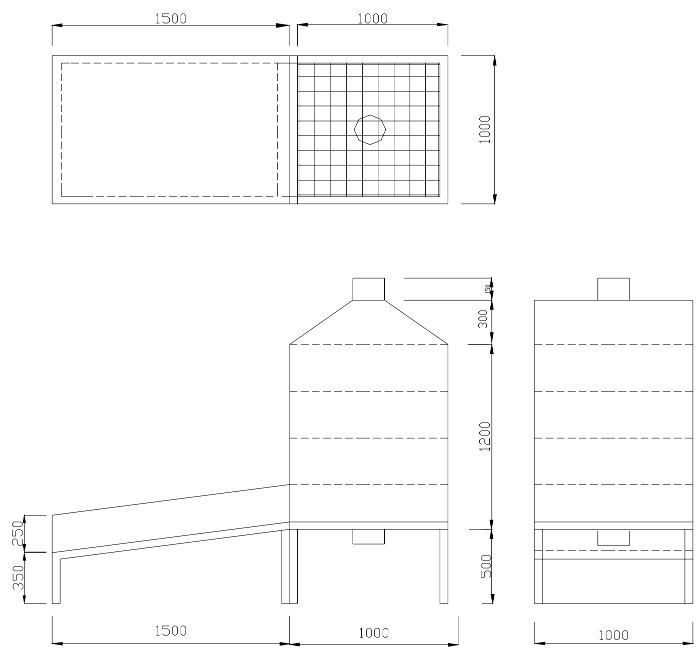
	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Chamber	66(186)	41(70)	29(40)	17(20)	11(12)		
Outside	66(186)	50(100)	43(75)	29(41)	21(27)	16(19)	13(15)

Experiment 3

	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Chamber	66(197)	47(90)	31(45)	23(30)	13(15)		
Outside	66(197)	55(120)	44(80)	33(50)	26(35)	18(22)	11(12)

Comparison of Moisture Content variations for experiments 1, 2 and 3.

Experiments	Day 0	Day 1	Day 2	Day 3	Day 4
Experiments 1	178	45	22	13	8
Experiments 2	186	70	40	20	12
Experiments 3	197	90	45	30	15



Orthographic views of the solar dryer (All dimensions in mm).