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Development of a Solar Concentrator Dryer with an Electronic Monitoring System for Evaporating Moisture in Yam

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Abstract: *The development of a solar concentrator dryer using locally made materials consisting of three main components: the drying chamber, the solar collector and the absorber. A constructed measuring device with logger which is the electronic system was used to monitor the temperature, moisture content and light intensity during the drying process. The device consists of sensors for sensing temperature (LM 35), light intensity (phototransistor) and moisture level (moisture changing resistor). As the intensity of the sun increases, the temperature of the dryer begins to rise and the rate of evaporation in the solar concentrator dryer is higher the evaporation rate in the open sun. The dryer drying process reduced the moisture content of 500 g of sliced white yam from 73.20% (wet basis) to 4.29% (wet basis) for 20 hours despite the poor weather condition when the experiment was carried out.*

Keywords: *solar conconcentrator dryer, electronic monitoring system, yam*

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I. Introduction

The worrisome rate of unemployment and increase in population had necessitated the need for the government and private individuals to be involved in the cultivation of agricultural products such as maize, rice, beans, melon, guinea corn, tomatoes, pepper, plantain, yam, e.t.c.

Yam (*Dioscorea species*) are annual root tuber bearing plants with more than 600 species out of which six are socially and economically important in terms of food, cash and medicine (IITA, 2009 and *Verter and Becvarova*, 2015). The yam species include; Water yam (*Dioscorea alata*), white yam (*Dioscorea rotundata*), yellow yam (*Dioscorea cayanensis*), Chinese yam (*Dioscorea esculant*) e.t.c. (*Zaknayiba and Tanko*, 2013 and *Olubukola and Bolarin*, 2006). The preservation of agricultural products of high output yields at relatively low cost devoid of impurities have posed a great challenge. In order to overcome challenges associated with storage of agricultural products, there is an increasing demand for efficient and cost effective devices (dry units) for drying agricultural products (Fuwape *et al*., 2015). Proper drying will remove moisture and prevent wastages which will enhance safe storage of agricultural products for a long time. For effective drying system, confined solar drying system can be employed which will be hygienic and help to generate higher air temperatures. As a result, the risk of sand and waste found in drying products will be completely eliminated (Amunugoda *et al., 2013*).

The great economic importance of drying agricultural products by solar energy all over the world especially in Nigeria cannot be over-emphasized. The sun radiates an enormous amount of energy called solar energy. Solar energy is abundant and this energy comes from the sun. Solar energy is a nuclear fusion reaction taking place inside the sun; these reactions convert hydrogen nuclei to helium nuclei. The energy released as a result of these reactions is radiated by the sun in all directions (Fuwape *et al.*, 2017). Any object in space that intercepts this radiation receives direct solar radiation. Solar radiation reaching the earth is the main driving force of natural processes taking place on the earth. (Bhattacharya and Kumar, 2000)

The sun creates its energy through a thermonuclear process that converts about 650,000,000 tons of hydrogen to helium every second. The process creates heat and electromagnetic radiation. The electromagnetic radiation includes; radio waves, microwaves, heat (infrared radiation), visible light, ultraviolet light, x-rays and gamma rays. The sun emission contain the following: visible light, infrared light and ultra-violet radiation streams out into space in all directions. It means that sun releases electromagnetic radiation to the earth. (Brown, 1988).

The radiation type wavelength range, frequency range, energy (eV) range and the temperature of objects at which all these radiations are the most intense wavelength emitted are shown in figure1.

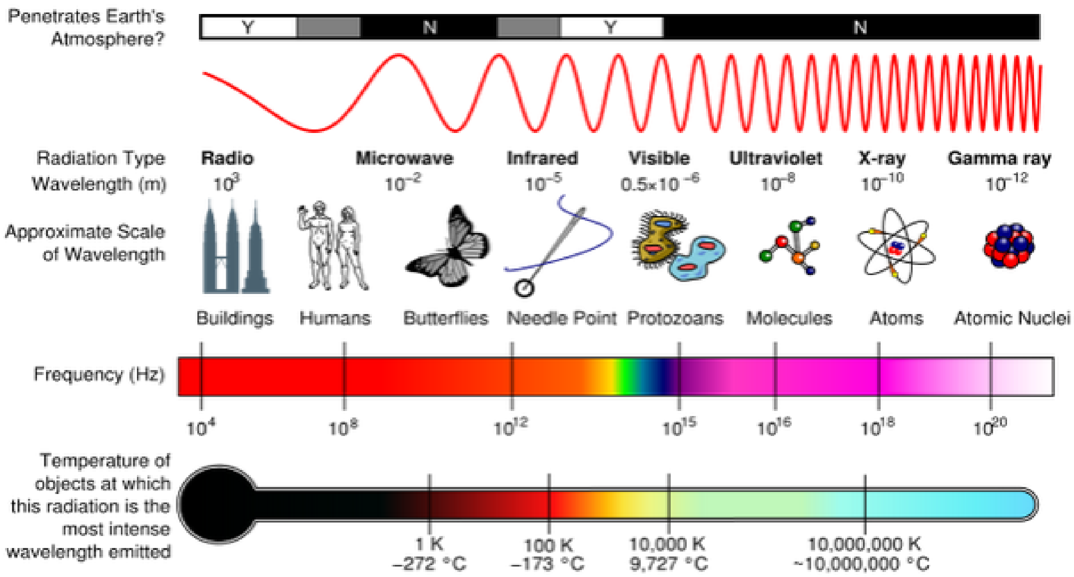

Figure 1: Electromagnetic Spectrum

Source: Nikita, 2014.

Drying of agricultural products can be achieved using open sun drying system (Traditional method) and modified enclosure sun drying system (solar drying). Traditional method of drying agricultural products makes the products to be easily contaminated with fungi, bacteria, dust, birds, rain, insects, pests etc. This makes the products unhealthy for consumption. For proper preservation of agricultural products, there is dire need to create artificial drying unit that will depend solely on the natural source of energy (solar energy).

Onigbogi *et al*., 2012 designed and constructed a solar dryer of dimensions 94cm x 45cm x 101cm / 20cm (length x width x height) using locally available materials. 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. Ringeisen *et al*., 2014 investigated the effectiveness of adding a concave solar concentrator built from low-cost, locally available materials to a typical Tanzanian solar crop dryer. Drying trials using Roma tomatoes with initial moisture content of approximately 90% were dried at 10% moisture content. The concentrator proved to be effective, reducing drying time by 21% in addition to increasing internal dryer temperature and reducing relative humidity. Akowuah *et al*., 2012 used a scale tunnel dryer and open sun drying to investigate the effect of drying air temperatures (45°C, 50°C, 55°C and open sun drying) and post-drying duration on fissuring and head rice yield of a local long grain rice variety. It was presumes that paddy rice can be dried at temperatures of 45°C and 50°C using a mechanical dryer when the harvest and raining season coincides. Babamiri and Asli-Ardeh, 2013 observed the effect of drying temperature and final grain moisture content on the hulling and head rice yield efficiency of some common rough rice varieties. In drying process, drying temperature and final moisture content of grain are important factors that affect grain strength and consequently the waste of rice milling. Folaranmi, 2008 designed a solar dryer in such a way that solar radiation is not incident directly on the maize, but preheated air warmed during its flow through a low pressure thermosphonic solar energy air heater or collector, absorber plate and a cover glass all arranged. The test results gave temperature above 45^{O}C in the drying chamber, and the moisture content of 50kg of maize reduced to about 12.5% in three days of 9 hours each day of drying. Potdukhe and Thombre, 2008 designed and fabricated a solar dryer with an absorber having inbuilt thermal storage capacities. The thermic oil was used as a storage material. It reduces the drying period and enhanced the quality of dried product mainly chillies and fenugreek leaves. Diamante and Munro, 1993 used an indirect solar dryer to study the drying of sweet potato slices. The solar drying rate curves exhibited a constant rate period and one linear falling rate period. A mathematical model for solar drying of sweet potato slices was derived based on the simplified form of the Fick's diffusion equation. The mathematical model could satisfactorily describe the solar drying of sweet potato slices to moisture content below 20% dry basis.

II. Theoretical Background

Estimation carried out to determine the placement of the solar concentrator dryer and the basic parameters obtained to determine efficiency of the solar concentrator dryer are;
The angle of tilt (β) of the solar collector is given as

$\beta = 10^0 + lat\phi$ Alamu et al, (2010) (2.1)

Where $lat\phi$ is the altitude of the collector location. The latitude of the location in the Federal University of Technology, Akure is 7.2^0. Hence, the angle of tilt of the dryer is $10^0 + 7.2^0 = 17.2^0$.
The quantity of heat required to dry the agricultural products at moderate temperature can be estimated by

$Q = M_w L = \rho c_\rho V(T_a - T_b)$, Gatea, (2011) (2.2)

where L is the latent heat of vaporization of water, M_w is the mass of the crop before drying (kg), ρ is the density of water (kg/m^3), c_ρ is the specific heat capacity of water (J/kgK), V is the volumetric flow rate. (m^3/s), T_a is the ambient temperature, T_b is the dryer temperature.
The dryer efficiency (η_d) can be obtained from the expression

$$\eta_d = \frac{M_w L}{I_c At} = \frac{\rho c_\rho V(T_a - T_b)}{I_c At}$$ Ajao and Adedeji, (2008) (2.3)

where I_c is the sun intensity on the collector (W/m^2), A is the surface area, (m^2) t is the time spent for drying, ρ is the density of water (kg/m^3), c_ρ is the specific heat capacity of water (J/kgK), V is the volumetric flow of rate. (m^3/s), T_a is the ambient temperature, (^0C), T_b is the dryer temperature, (^0C), M_w is the mass of the crop before drying (kg) and L is the latent heat of vaporization of water.
The moisture content (MC) of the crop can be obtained using the expression

$$MC(\%) = \frac{M_i - M_f}{M_i} \times 100\%$$ (wet basis) Gatea, (2011) (2.4)

where M_i is the mass of the crop before drying and M_f is the mass of the crop after drying.
The drying rate (DR) can be obtained through the expression

$$DR = \frac{dM}{dt}$$ Mohanraj and Chandrasekar, (2009) (2.5)

where dM is the change in mass of the crop and dt is the change in drying time.

III. Materials and Methods

The materials used for the construction of the solar concentrator dryer in figure 2 are: wood, aluminium sheet, aluminium foil, convex lenses, polythene, wire mesh, net, black paint, iron nails and hinges. The solar concentrator dryer consists of three main components: the drying chamber, the solar collector and the absorber. The drying chamber is made of wood which helps to minimize the heat loss by radiation with air inlet and outlet allows air to circulate through the system to remove water vapour from the drying products according to Fuwape *et al*., 2017.

The convex lenses are the solar collectors which increase the amount of incident energy on the absorber surface. Incident rays of light from the sun fall on convex lenses and converges the rays at the focal point which generate heat for heating the drying products spread in the dryer. Polythene is used to cover the convex lenses arranged on the wire mesh to prevent the heat from escaping from the dryer and also to prevent rain from falling on the dryer. The collector is tilted and oriented in such a way that it receives maximum solar radiation. Aluminium sheet is used as an absorber because it has high thermal conductivity and high resistance to corrosion and respond quickly to the absorption of solar radiation according to Bolaji and Olalusi, 2008. The absorber is made of aluminium metal sheet coated black. It has a thickness of 0.65mm and dimension of 0.8 m x 0.69 m. The aluminium sheet is placed below the convex lenses to absorb the incident solar radiation and heating the air between it.

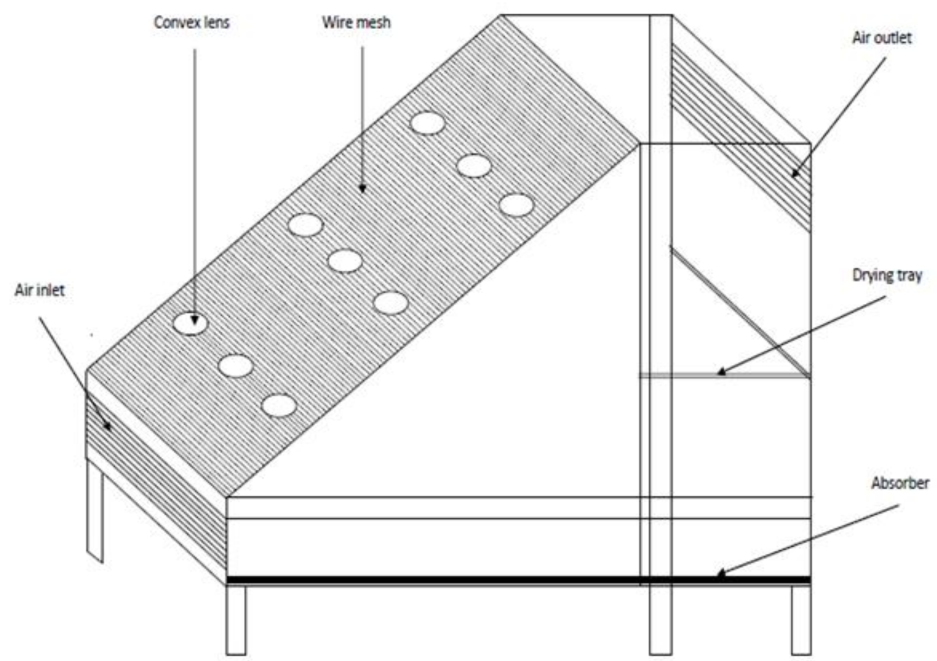

Figure 3: Schematic diagram of the solar concentrator dryer.

3.1 Electronic System

A constructed measuring device with logger is incorporated to measure the following parameters; temperature, light intensity and moisture level during the drying process. The device consists of sensors for sensing temperature (LM 35), light intensity (phototransistor) and moisture level (moisture changing resistor). Microcontroller (arduino), analog to digital converter is linked to the storage medium (memory card) and display unit.

The electronic system consists of sensors that sense the temperature, moisture content and light intensity in analog form. These signals are fed to analog-to-digital (ADC) converter that changes the signals into voltage which serve as the input signal to the microcontroller (arduino). The arduino is programmed to sense and capture data at an interval of one hour sampling time for temperature, moisture content and light intensity. The data captured in the microcontroller is stored in a one gigabyte SD card (memory card) as a backup device. The system has the capacity to display data value at in-situ on the liquid crystal display (LCD).

3.1.1 Light Intensity Sensor

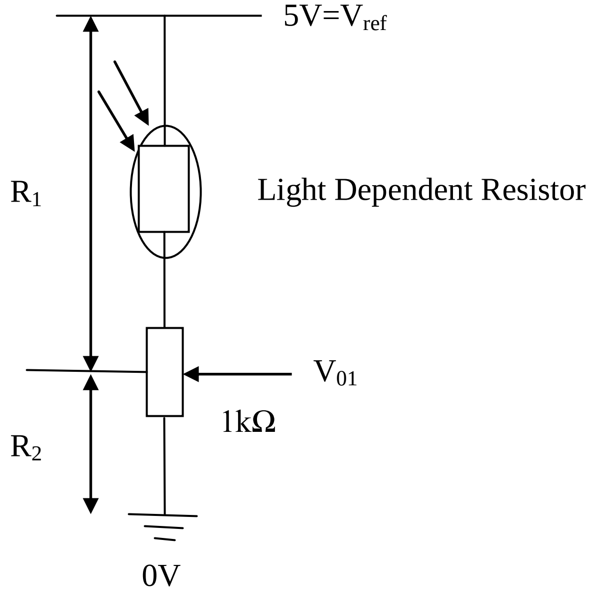

Figure 3.1.1: Light Intensity Circuit

The Arduino analog inputs are visible to the light dependent resistor (LDR). The voltage output (V_{01}) in Figure 3.1 changes with light intensity incident on the light dependent resistor (LDR). There will be voltage develop across the resistance, R_2, as light falls on LDR. The voltage (V_{01}) developed is proportional to the light intensity. The voltage developed is given in equation (3.1) below

$$V_{01} = \frac{R_2}{R_1 \times R_2} \times V_{\mathrm{Re}\,f} \qquad (3.1)$$

3.1.2 Moisture Content Sensor

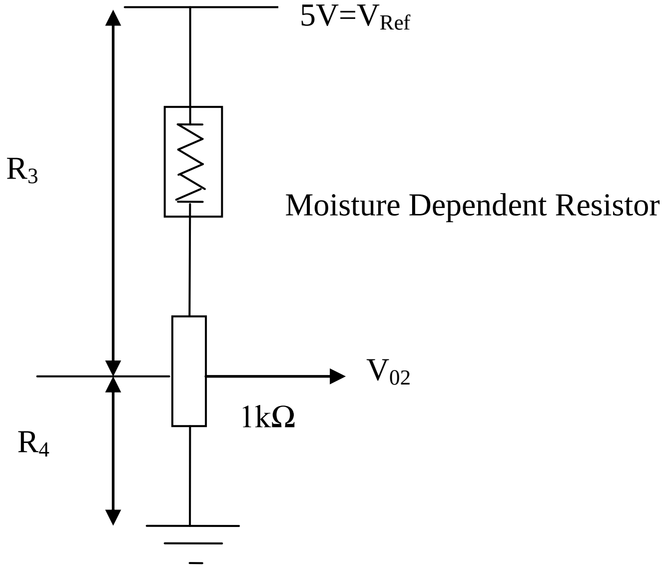

Figure 3.1.2: Moisture Content Measurement Circuit

The output voltage (V_{02}) in Figure 3.2 changes with moisture content received on the moisture dependent resistor (MDR). More voltage will develop across resistance R_4 when the sensor receives moisture content from environment. The output voltage (V_{02}) is proportional to the amount of moisture content in the system. The operation of circuit in Figure 3.2 follows equation (3.2)

$$V_{02} = \frac{R_4}{R_3 \times R_4} \times V_{\mathrm{Re}\,f} \qquad (3.2)$$

3.1.3 Temperature Sensor

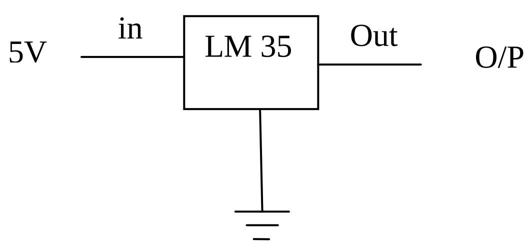

Figure 3.1.3: Temperature Circuit

The LM 35 is an integrated-circuit temperature sensor, with an output voltage linearly proportional to the centigrade temperature. The output voltage increases as the temperature rises. The output voltage in Figure 3.3 changes with temperature received on the LM 35. It has a standard calibration of 10mV which is equivalent to 1^0C.

3.2 Experimental Procedure

White yam was used as the sample for the experiment which was carried out on 6th to 8th of July, 2015. The white yam was peeled and sliced into chips. The solar concentrator dryer was position outside with the collector facing the direction of the sun. 500g of the sliced yam with an average thickness of 4.0mm was spread on the tray in the drying compartment box of the solar dryer. Also, 500g of sliced yam were dried in the open sun as the control experiment. An electronic device was used to monitor the temperature and the moisture level during the drying process.

IV. Results and Discussion

4.1 Drying Temperature of Sliced Yam

Figure 4.1 reveals that as the intensity of the sun increases, the temperature of the dryer begins to rise and the evaporating rate begins to increase. The results obtained during the drying process revealed that the temperature inside the dryer were much higher than the open sun temperature during most hours of the day-light. The dryer is very hot when the sun is usually overhead. The dryer exhibited sufficient ability to dry agricultural products rapidly to a safe moisture level and ensured quality of the dried products.

4.2 Moisture Content

Figure 4.2 shows that the moisture content of the sliced yam was very high during the initial phase of the drying which resulted in higher drying rates. Drying rate increased with the increase of drying temperature. As the drying progresses, the loss of moisture in the product decreases and result in a fall in the drying rate. This result is in agreement with previous studies Rayaguru and Routray, (2011); Maskan, (2000). The dryer drying process which reduced the moisture content of sliced Yam from 73.20% (wet basis) to 4.29% (wet basis) for 20 hours. Figure 4.4 shows that there is a constant drying rate terminated at the critical moisture content followed by falling drying rate. The drying rate decreased till the moisture content reached equilibrium then the drying rate became zero. The period of constant drying rate is short and the falling rate period depends on the rate at which the moisture is removed.

Figure 4.3 shows that the period of falling rate started from 1 hour to 16 hours of drying while the remaining period is constant. Figure 4.7 is similar with the curve reported in the literature in the drying of cocoa beans Fagunwa and Koya, (2009).

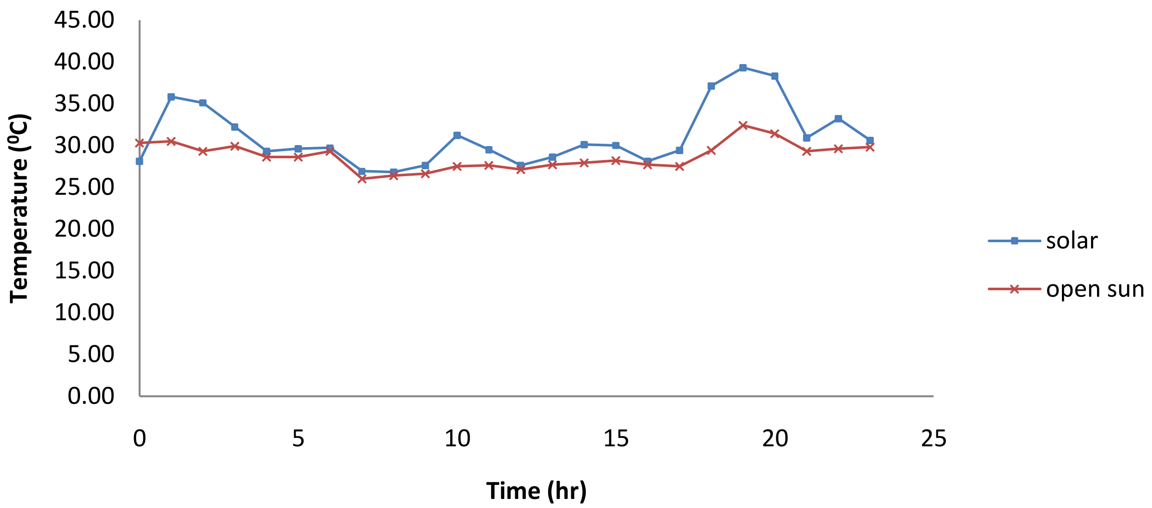

Figure 4.1: Variation of temperature of sliced Yam in the solar concentrator dryer and open sun

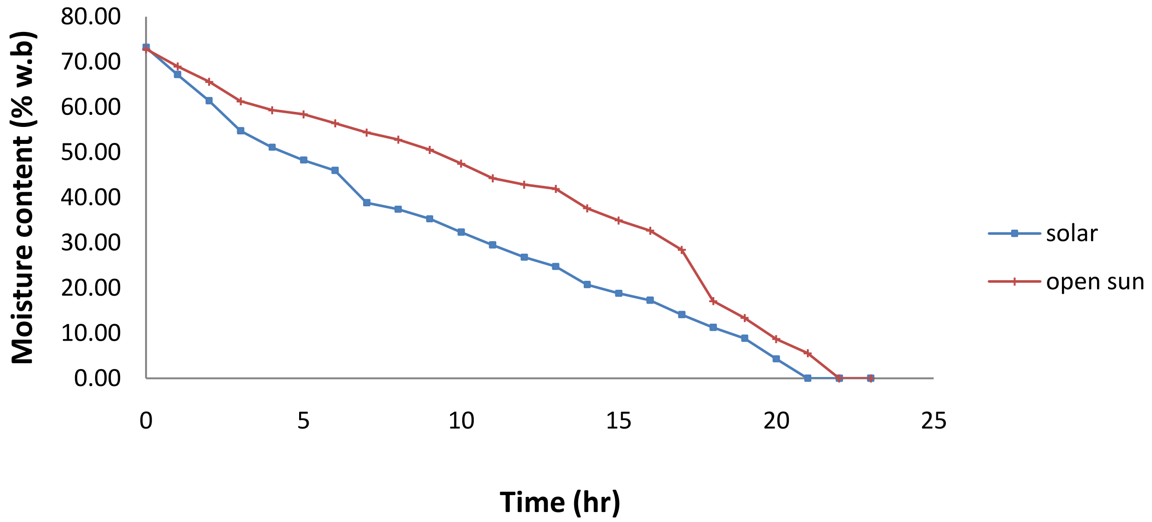

Figure 4.2: Variation of moisture content of sliced Yam in the solar concentrator dryer and open sun

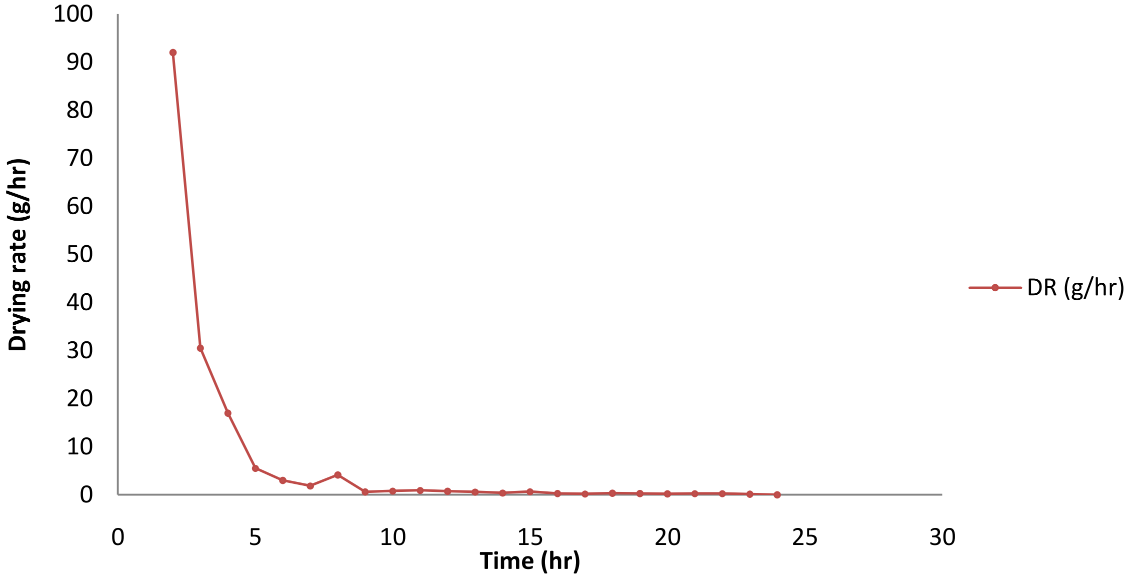

Figure 4.3: Drying rate with time of sliced Yam in the solar concentrator dryer

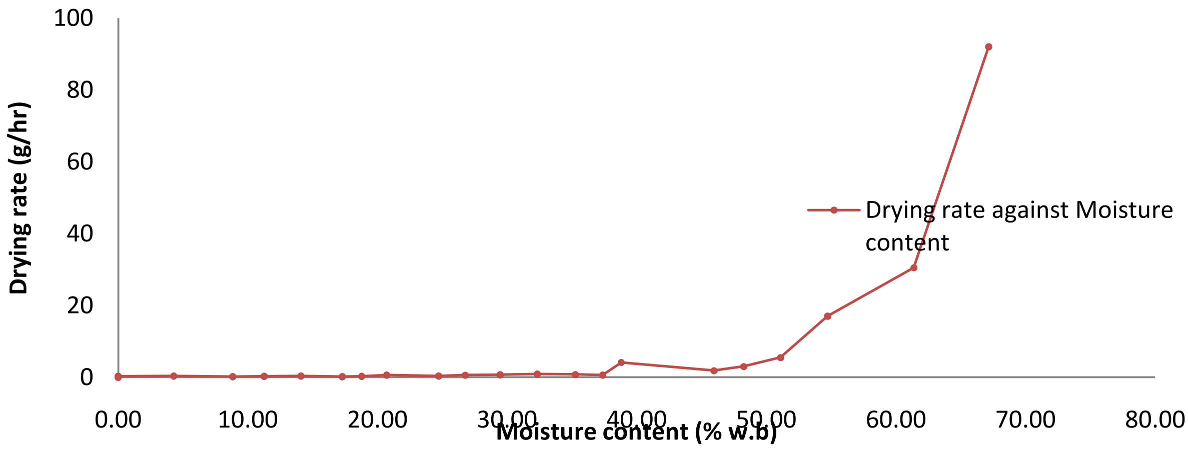

Figure 4.4: Drying rate with moisture content of sliced Yam in the solar concentrator dryer

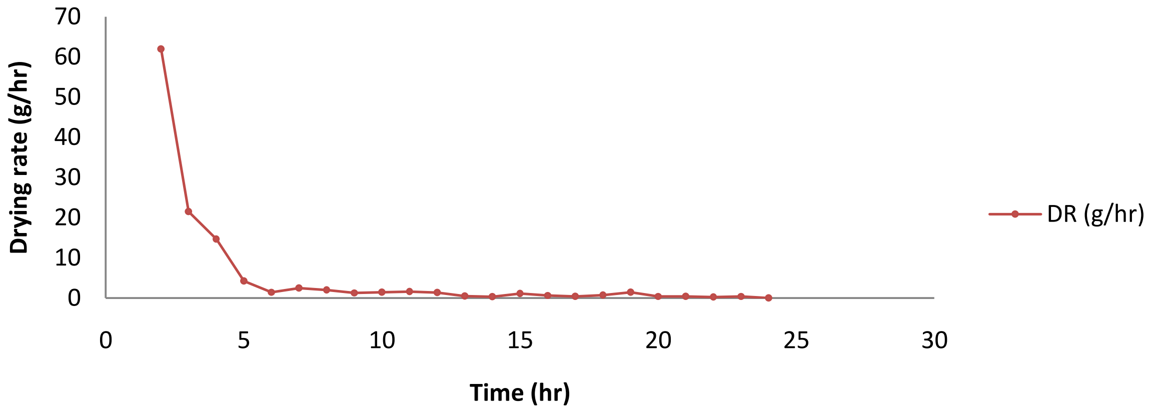

Figure 4.5: Drying rate with time of sliced Yam in the open sun

V. Conclusion

The three main components of the solar concentrator dryer are; the drying chamber, the solar collector and the absorber which provide a uniform drying process. The electronic system monitored the temperature, moisture content and light intensity during the drying process. As the intensity of the sun increases, the temperature of the dryer begins to rise and the evaporating rate in the solar concentrator dryer is higher the evaporating rate in the open sun. The dryer drying process reduced the moisture content of 500 g of sliced white yam from 73.20% (wet basis) to 4.29% (wet basis) for 20 hours despite the poor weather condition in the month of July, 2015 when the experiment was carried out.

There was no exposure to animals, flies and dust concentrations in the solar concentrator dryer which make the dried yam to be healthy for consumption. The solar concentrator dryer becomes affordable to the local farmers because it was developed using locally made materials.

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