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Controlling the Periodic Heat Flux of Solar Radiation into an Adobe Storage System for Onions: Part (i) – Effect of Sealed Water-Pond

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ABSTRACT*:* A model experimental adobe room with and without water pond on its roof was investigated in Sokoto. Solar radiation, outer walls and inner walls temperatures, ambient as well as room temperatures and relative humidity were measured in order to ascertain the best room for onion storage. It was found that adobe room without roof pond has lower range of room temperatures compared with the room with roof pond. The internal temperature of room (with or without water pond) is less than the ambient temperature during the sunshine hours of the day but converse is the case in the night hours. Furthermore, in the early morning hours the ranges of internal relative humidity for the room are within the range suitable for onions storage.
Keywords: Heat flux, Temperature, Relative humidity, Adobe room, Roof pond.

I. INTRODUCTION

Onion is one of the most important vegetable crop of the world and a high propotion of the world onion production take place in the tropical region [1]. In Nigeria, commercial onion production is mainly in the North, with an estimated land area of 0.1- 0.2 million hectares cropped annually [2]. Sokoto state is one of the leading onion producing states in the North [2]. Although onions are produced in large quantities, adequate attentions have not been given to its storage and preservation [1]. For instant, the price of a 100kg bag of onion is about 4000 during harvesting but rises to about 40,000 few months later. This is because there are several storage problems of rapid rotting and sprouting under the hot dry and cool harmattan condition respectively. The fact that the market cannot absorb supplies of large quantities of onions and the stability of demand for the vegetable throughout the year leads to the renewed effort at understanding the best way of storing the commodity, so that the local farmers can benefit from the fruit of their labours. From the survey conducted by the authors among farmers in Sokoto, Kebbi and Zamfara states, it shows that onion preservation and storage in large quantity posed a difficult task to farmers due to humidity and temperatures obtained in the areas.

There are different modes of onion storage system, among which are Dutch method, Lofts method and Ventilated building method [3]. In Nigeria today, and Sokoto in particular, the commonest storage is the ventilated building method. This is usually done 'in batch' stores using slatted floor upon which are placed 1m deep layers of onions or in deeper stores either in barns using on the floor ventilation or in bins as done for grains drying [3]. However, with climatic situation in Sokoto-hot/dry during dry season and cold conditions during rainy and harmattan seasons, coupled with the poverty level of the inhabitants of the area, damages to the onion bulbs were inevitable since the desired storage conditions of 25-30^{o}C/65-75^{o}RH [4] were not maintained in all these instances of storage. According to literature [4], a good onion store should achieve and maintain the desired storage condition of either 0^{o} – 5^{o}C, 65-75%RH or 25-30^{o}C, 65-75%RH. A high RH (in excess of 75%) is a prime enemy of good onion storage as it promotes root growth and development of storage pathogens while a low humidity (less than 65%) in contrast, leads to excessive moisture loss from the bulbs resulting in shrivelling and loss in weight. Furthermore, sprouting which is regarded as the second most damaging occurrence during storage after rotting is usually favoured at temperature above 30^{o}C. Unfortunately, for Sokoto and environs, the ambient climatic environment often falls within these unfavourable storage conditions. For instance, Sokoto has a record annual maximum and minimum temperature of 30-42^{o}C and 20-25^{o}C in the dry and wet season respectively, average relative humidity of 45%RH and annul global solar radiation of 5.5-6.0kW/m^{2}/day [5, 6]. Hence, when considering the stability of either an existing or a planned onion storage system for Sokoto, the primary concern should be to decide on how effective the system can be improvise to achieve and maintain the desired storage conditions, taking into consideration the climate factors and the available resources.

Solar pond for simultaneous collection and storage of solar energy has been known for some time [7, 8]. It has been proposed for space heating [7, 9], process heating [7, 10] and desalination [11]. This work is part of a research programme investigating various ways of controlling the periodic flux of solar radiation into an adobe storage system for onions. In the previous work [12], adobe room with either insulation or double hollow roof had their internal air temperatures reduced by about 5^oC. In addition their humidity was below 65% which may not lead to spoilage but can lead to weight loss. In this paper solar pond is been used in controlling the fluctuation of temperature in the adobe store for onion storage. It is hoped that this work will help to establish a proper storage condition for onions in Sokoto and environs.

II. EXPERIMENTAL METHOD

The experimental method involved experimental set-up and data acquisition which are as follow:

2.1 Experimental set-up

Three adobe rooms each of dimension 2x2x2m, labelled 1, 2 and 3 were constructed with mud blocks at the Sokoto Energy Research Centre, Usmanu Danfodiyo University, Sokoto (see figure 9). The West, South and East walls contain two windows for ventilation (one at the top and one at the bottom) as the roof is 4m^2 in area. The West, South and East walls contain two windows for ventilation (one at the top and one at the bottom), each of 0.04m^2 in area. The North wall has one similar window at the top and a door of area 0.25m^2 at the bottom. (See figure.1)

Room 1 and 2 has 10cm and 5cm - water pond respectively on their roofs while room 3, otherwise known as control room has no water pond on its roof.

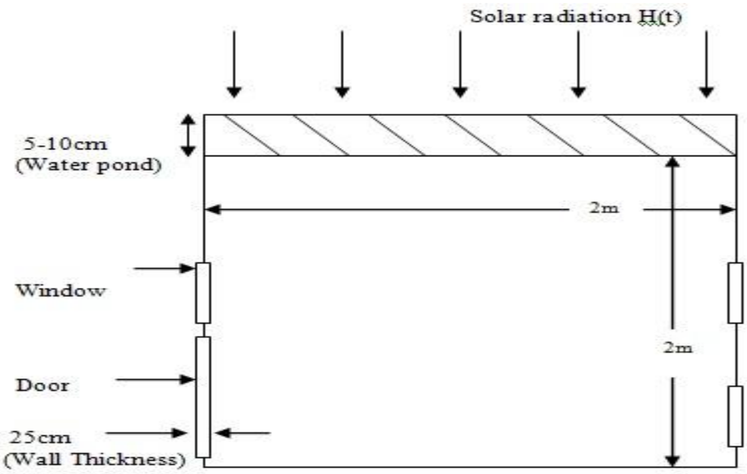

Figure 1 Schematic cross-section of experimental adobe room with water pond on its roof.

2.2 Data acquisition

The temperature of the inner and outer wall surfaces, temperature and relative humidity for the ambient and inside rooms, were measured using digital thermocouple, mercury-in-glass thermometer and dry-and-wet bulb thermometer respectively. A digital automatic data logger made by Delta-T-instrument Company was used to obtain data for the diffuse and global horizontal solar radiation, outside air humidity, ambient temperature, wind speed outside the rooms and wind direction. All measurements were made at hourly interval for one week 5-11th June 2000.

III. RESULTS AND DISCUSSION

A number of physical measurements were carried out on the constructed adobe rooms for one week. In this report, performance results for two typical hot days namely 7th and 10th of June, 2000 to represent the days the rooms were not loaded with onions and the days the test rooms were loaded each with a 50kg of onion respectively were reported and discussed. The two days can also be said to represent Sokoto and environs harsh climatic conditions for most of the year.

Figures 2 and 3, shows the measured hourly global horizontal radiation and the calculated values for the four walls of the storage rooms on the 7th and 10th of June, 2000 respectively. The calculated values were obtained by using the relation [13]:

$$H_T = H_b R_b + \left[\frac{1+\cos\beta}{2}\right] H_d + \left[\frac{1+\cos\beta}{2}\right]\left(H_b + H_d\right)\rho_d \qquad (1)$$

The effective incidence (R_b) is given by

$$R_b = \frac{\cos \vartheta_T}{Sin\alpha} \quad (2)$$

Where $Cos\vartheta_T$ = Sinϕ Sinδ Cosβ - Sinδ Cosϕ Sinβ Cosγ + Cosϕ Cosδ Cosω Cosβ + Cosδ Sinϕ Sinβ Cosγ Cosω + Cosδ Sinβ Sinγ Sinω (3)

And Sinα = Cosϕ Cosδ Cosω + Sinϕ Sinδ (4)

Where α ,ϕ, β and ω are longitude, latitude, altitude and hour angle respectively, the declination

δ = 23.45 Sin [360 (284 + *n* / 365.25)] (5)

And *n* is the day number.

Figure 2 and Figure 3 shows that the global horizontal radiation, GH, was zero during early morning, and late nights, it was high during midday between 9.00 and 18.00 hours. In-fact, for the two days, it makes the same usual parabolic curve between the hours of 7.00 am and 20.00 pm local time with a peak value of 1,200 Wm^{-2} at 12.00 noon.

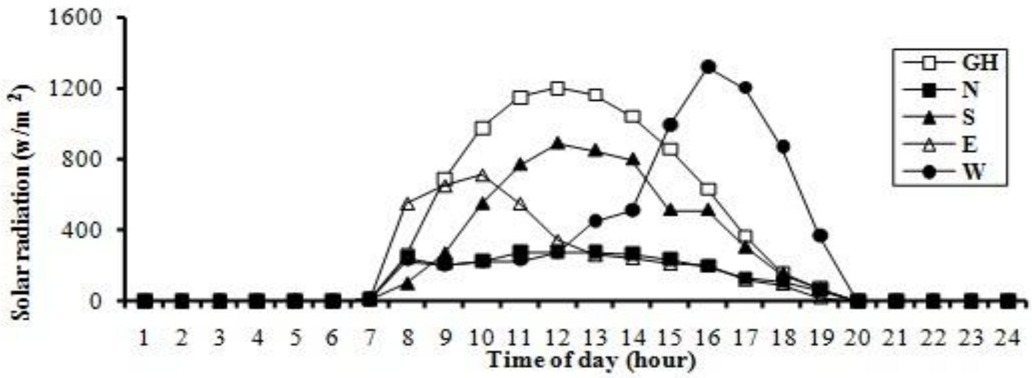

Figure 2 Measured Global horizontal radiation (GH) and Calculated values for the four walls of the test room on 7-6-2000.

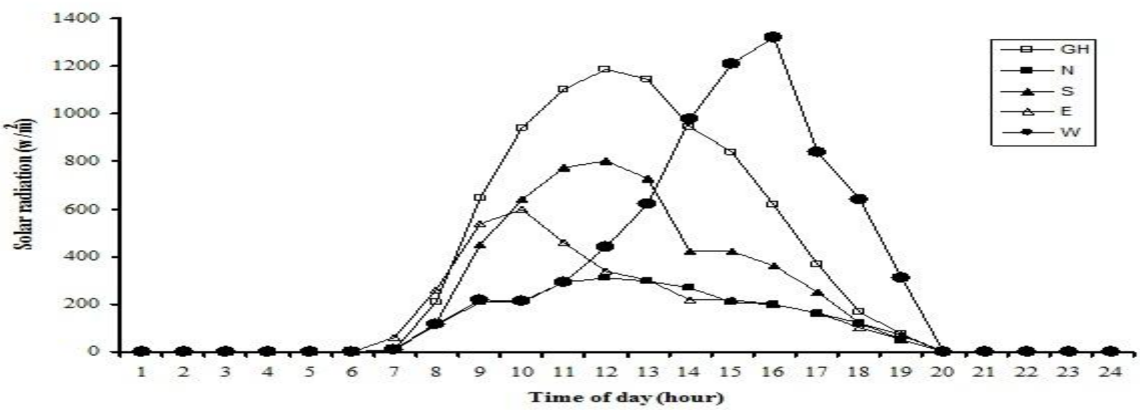

Figure 3 Measured Global horizontal radiation (GH) and calculated values for the four walls of the test room on 10-6-2000.

Figure 4 shows the wind speeds against time for the two days of 7th and 10th June, 2000. The result shows that the wind speeds for 7th June 2000 is higher than 10th June 2000. However both days were windy during midday between 10.00 and 18.00 hours local time. This is actually when ventilation is most required. The rate of ventilation affects the inside air temperatures of a room [14].

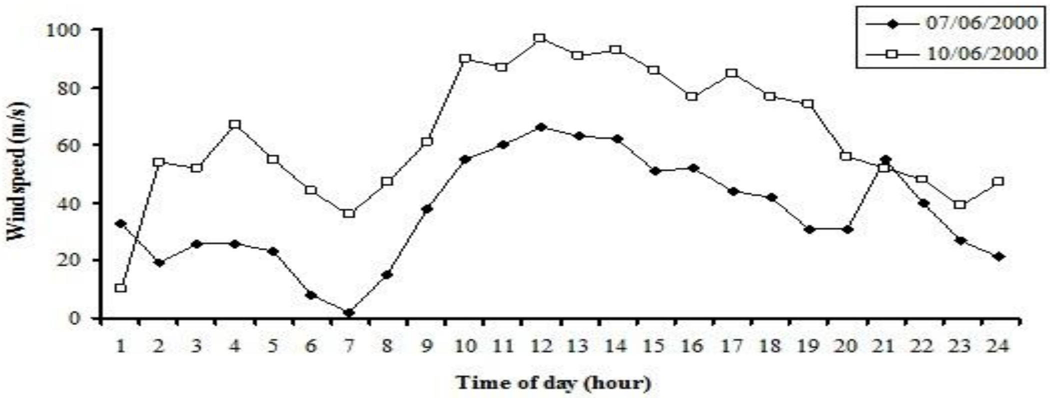

Figure 4 Ambient wind speeds on 7-6-2000 and 10-6-2000.

Figure 5 and Figure 6 shows that between late evenings; 18.00 hour and early morning 10.00 hour for both days of measurement, test rooms conditions approximate the required condition of relative humidity 65% - 75% [4]. Only in the midday between 10.00 and 18.00 hours did the relative humidity of the rooms fall below the required minimum condition of 65%. The rate of fall is more when onions were loaded as in figure 6. However, incorporating water pond reduces the rate of fall of relative humidity especially on 7[th] June, 2000, when onions was not loaded.

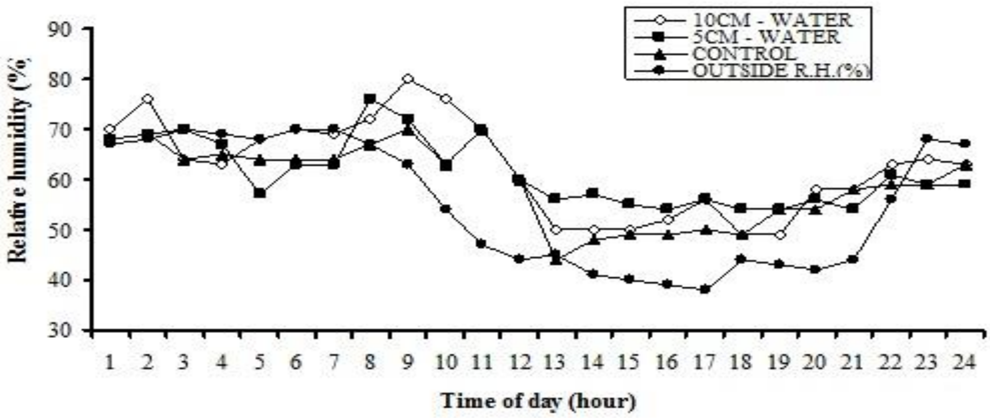

Figure 5 Plot of outside air relative humidity and inside air relative humidity for the three rooms under test on 7-6-2000.

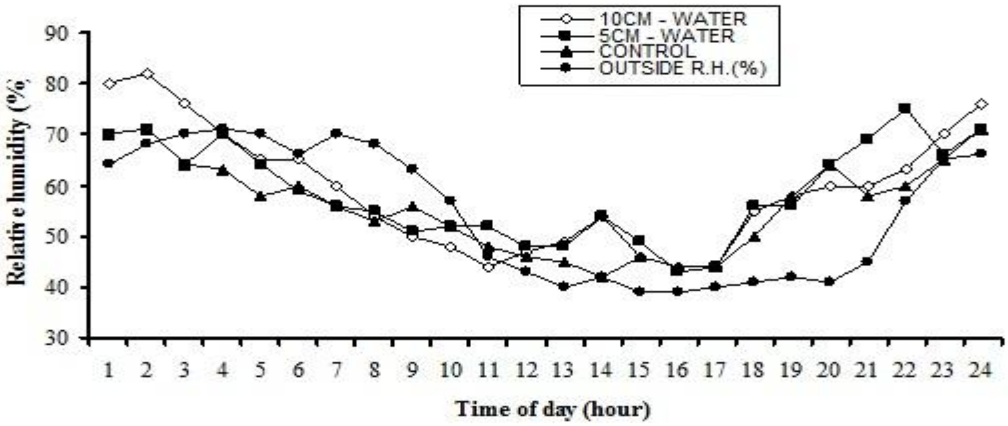

Figure 6 Plot of outside air relative humidity and inside air relative humidity for the three rooms under test on 10-6-2000.

Figure 7 and Figure 8 shows the outside air temperature (ambient) and the measured inside temperature for the rooms on the 7[th] and 10[th] June, 2000 respectively. As expected for adobe structures the inside of the rooms were relatively cooler than the ambient air [15]. As evident in figure 8, systems could keep the temperatures within the range of 28 - 32^{o}C when onions was loaded, while for day without onions the room temperature range was between 26 to 30^{o}C which falls within the required range for the proper preservation of onions, is plausible to suggest that adobe structures with sealed water pond could be use for onion storage around Sokoto and environs.

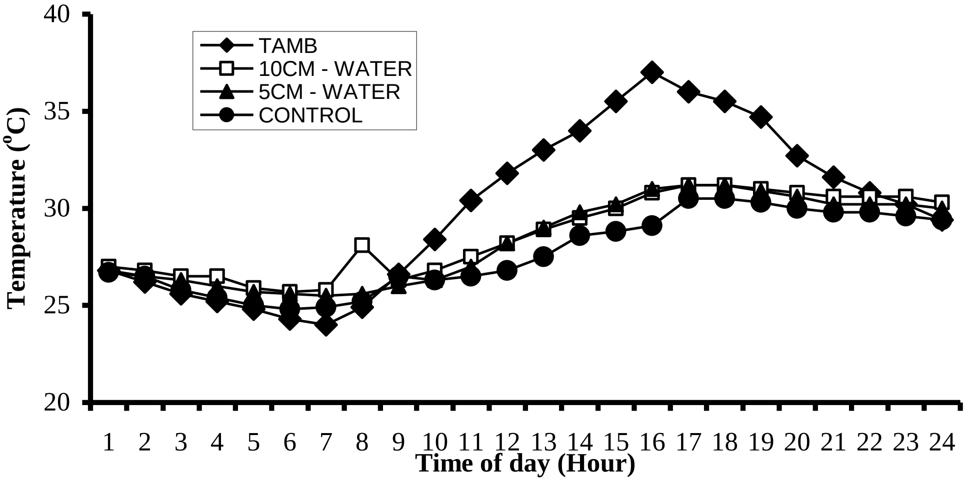

Figure 7 Measured ambient air temperature and inside air temperature for the three rooms configurations under study on the 7 – 6 – 2000.

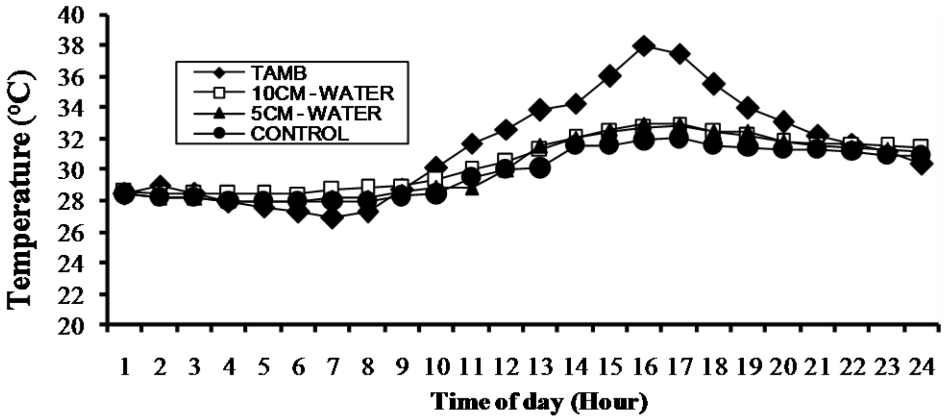

Figure 8 Measured ambient air temperature and inside air temperature for the three rooms configurations under study on the 10 – 6 – 2000.

The result of the control room shown in figures 7 and 8, indicate a slightly better performance than the water pond rooms. According to the previous report [15], the simplest reason could be that the presence of onions in the room leads to desiccation, which raised the internal room temperature of the storage systems. The water pond perhaps only aided in trapping the heat so generated since conduction through the walls would be reduced by the presence of the insulator.

IV. CONCLUSION

A model experimental adobe room with and without sealed water pond on its roof was investigated. The inner walls and ambient temperatures as well as relative humidity and solar insolation were measured to determine the setting that is best fit for storage of onions. The results show that the room with water pond has higher range of internal temperatures, which may be due to lack of escape of water molecules (by evaporation) from the pond.

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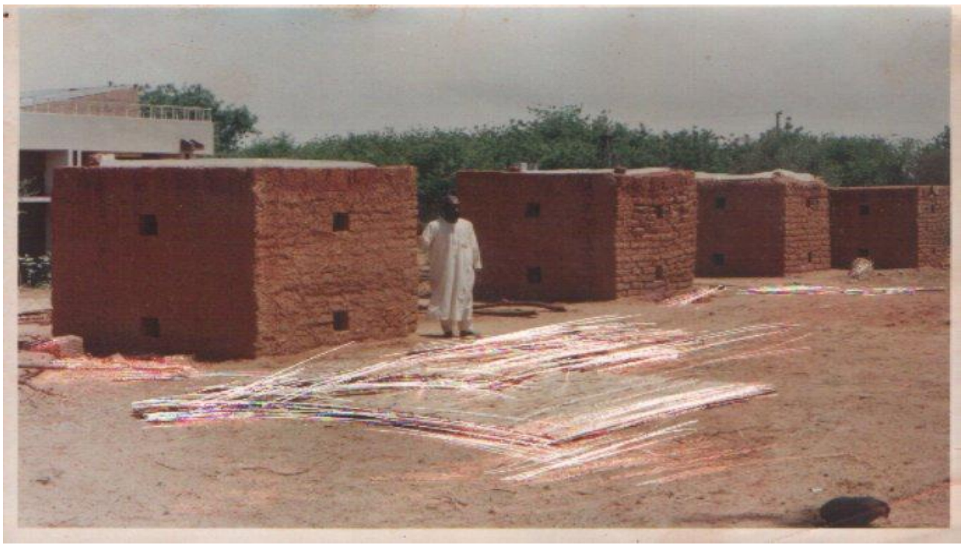

Figure 9 Experimental adobe test rooms