Development of an Energy Storage Chamber to Enhance Solar Drying of Grain at Night

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Abstract

Solar drying is the one of the effective means for preserving grains and pulses. It is a simpler, cleaner and safer method of drying. However, most available solar dryer are inefficient due to non-availability of solar energy during period of low insolation which eventually leads to moisture re-absorption with pronounced effect particularly at night, causing growth on dried grains. To solve this problem, an energy collector and storage chamber was developed and connected to a developed solar dryer to serve as heat source at night.

Surfaces of the collectors

No load test was carried out at night when the dryer was subjected to four different conditions: valve opened and collectors' surfaces covered; valve opened and collectors' surfaces uncovered; valve closed and collectors' surfaces covered; and valve closed and collector's surfaces uncovered. Load test was conducted by drying five different grains; maize, soyabean, groundnut, cowpea and sorghum during daytime using the dryer and applying the best combination of energy supplied and collectors' surfaces at night.

The result showed that the highest temperature difference of 35^0C and 33^0C were attained in the flat plate collector and drying chamber respectively, when the valve was opened and the collectors' surfaces were covered. The load test shows that there was slight reduction in moisture content of grains between 12 midnight and 5 am. The highest moisture reduction (4%) was recorded during drying of sorghum while the least moisture reduction (1%) was recorded when drying cowpea at night. In conclusion, for continuous solar drying of grains at night using stored energy, the valve controlling the heat storage chamber should be opened and the collectors' surface should be covered to obtain optimum temperature within the drying chamber. Conserved heat energy from the energy storage chamber ensures continuous drying of smaller grains (sorghum) and at least prevents moisture re-absorption in larger grains (cowpea and maize).

Keywords: Solar, Drying, Thermal-energy, Storage, Grains and Night

Introduction

Despite the readily availability of solar energy, its continuous usage has not been fully explored yet. This is due to the unpredictable nature of solar energies, resulting in varying thermal insolation at different times of the day. Studies on the solar intensity of different places on a typical day as reported by different researchers show that the day usually starts with low solar insolation (6am – 9am), follows by high insolation (12noon – 3pm) and then moderate insolation (4pm - 6pm). Thus, attaining high temperature particularly during period of low insolation may be difficult. If continuous drying requires to be achieved, solar dryer may be practically inefficient at night when there is no solar insolation. To effectively make use of solar dryer during this period, a suitable mean of thermal energy storage should be incorporated into the design of a solar dryer.

Such systems have been reported by various researchers (Abdullah and Gatea, A.A., 2011; Fagunwa, et al, 2009; Madhlopa and Nwagalo, 2007 and El-Sebaii, et al, 2002). These systems have heat storage units incorporated within the solar dryer. One major advantage of these systems is that during the day the heat storage increases the heat within the drying unit, increasing thus the efficiency of the system. However, at night when there is no solar insolation, the drying chamber loses its heat faster and because the heat energy storage is integrated within the drying chamber, there is loss of heat from the drying unit. Generally, when designing a solar dryer, the initial and the desired safe moisture content of the grain to be dried, the average available insolation in the area, the duration of drying, material of insolation, the condition of the surrounding air and the mean of collecting solar radiation should be considered.

The two basic devices used for collecting solar radiation are the flat plate collector and the parabolic collector. The basic components of a flat plate collector are the collector plate fitted with a passage for the working fluid, one or more transparent cover plates (glass or plastic) and the surrounding insulation. The collector absorbs incident radiation and transfers the energy to the working fluid. The cover serves to reduce radiative and convective heat losses from the hot surface of the collector plate. The insulation prevents heat loss to the surrounding air. On the other hand, a parabolic collector focuses the solar energy collected over a large area onto a small area. This focusing is only possible with the direct solar radiation and not with the diffuse long wavelength component one. The original ray that is parallel to the principal axis of a mirror is converged to a focus upon reflection. This point of convergence is called the focal point (Duffie and Beckman, 1991).

For any type of collector used, to optimize the energy collection, the surface which absorbs the solar radiation must be in a vacuum to avoid conduction and convection losses, the surface must have an absorption coefficient close to unity to maximize radiation collection, the surface of the collector must be able to absorb solar radiation with minimum attenuation and the surface which absorbs the solar radiation and all other parts of the system at elevated temperature in vacuum must have an emissivity close to zero. However, if a solar dryer with energy storage is to be developed, it is essential to also consider the major characteristics of a thermal storage system.

According to Kreider and Kreith (1981), the following should be considered when selecting material for thermal storage: its capacity per unit volume or weight, the temperature range over which it operates, the means of addition and removal of heat and the temperature differences associated therein, the temperature stratification in the storage unit, the power requirement, the means of controlling power losses from the storage and its cost. Different storage materials have been identified by different researchers, but gravel has peculiar characteristics that make it desirable for solar energy applications. The heat transfer between air and solid is high; the cost of storage material is low; the conductivity of the bed is low particularly when airflow is not present. Also gravel bed exchangers have high coefficient of heat transfer between air and solids of the bed; this tends to maximize temperature difference from air to solids on heating the bed, and solid to air on cooling the bed (Kreith and Kreider, 1978). Considering all these essential factors, this work aims at designing a standalone thermal energy storage chamber (parabolic collector) connected to a solar drying system (comprising of flat plate collector and drying chamber) to collect and store thermal energy using black coated gravel in order to prevent moisture re-absorption at night.

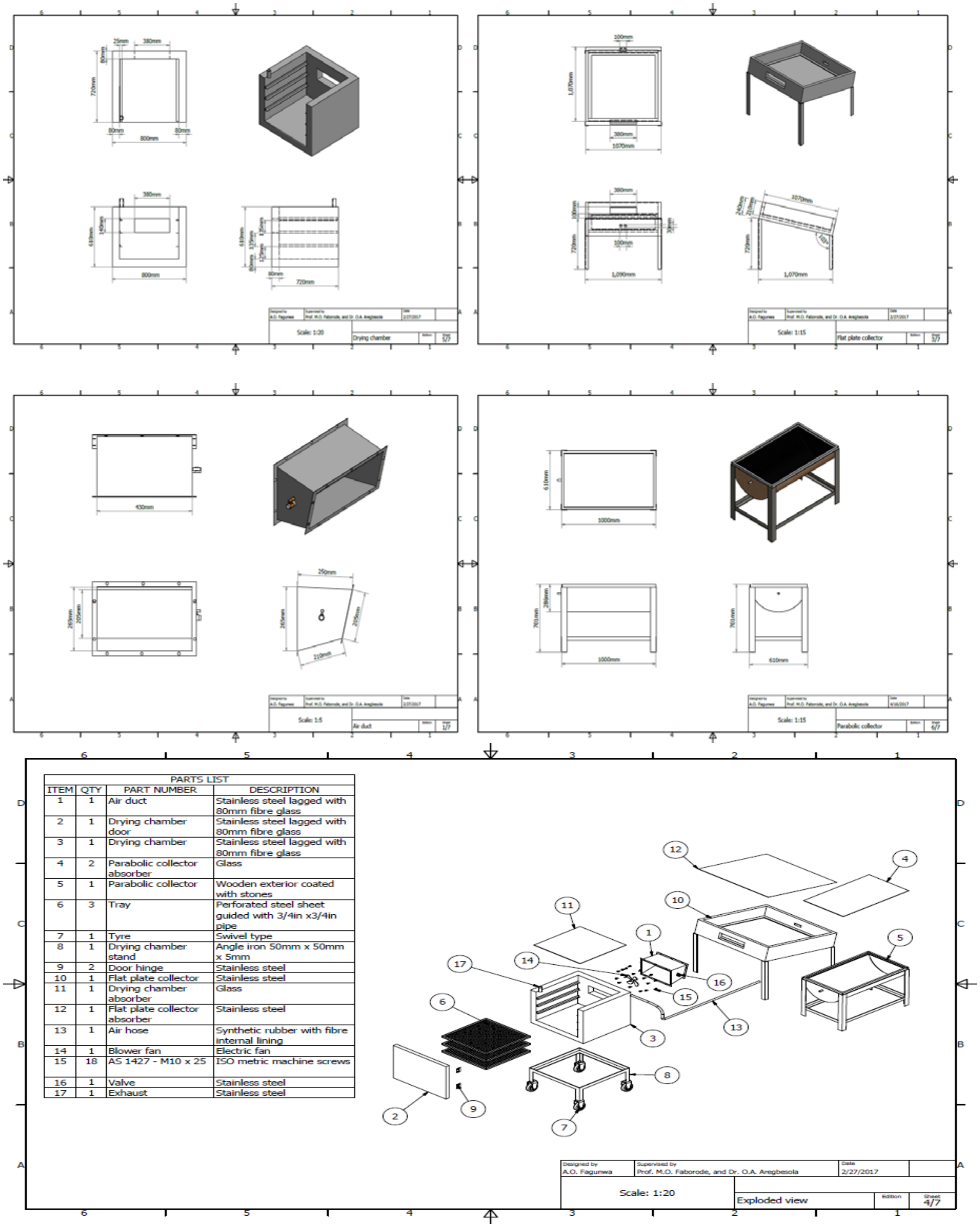
The Experimental Solar Dryer

The solar dryer (Figure 1) was designed and fabricated as a simple, low cost and easy to operate equipment that required little or no supervision during use**.** The isometric and exploded views of the different parts of the dryer are shown in Figure 2. The equipment was fabricated using stainless steel, which is not only suitable for food product but can also withstand harsh climatic conditions in the tropics. It basically consists of the flat plate solar collector, drying chamber, heat circulation unit (fan) and heat control unit (valve) and energy storage unit (parabolic collector).

Fig 1: The Experimental Solar Dryer

A – Flat Plate Solar Collector B – Parabolic Solar Collector (Heat Storage Chamber)

C – Drying Chamber D – Air duct Unit



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Air duct	Stainless steel lagged with 80mm fibre glass
2	1	Drying chamber door	Stainless steel lagged with 80mm fibre glass
3	1	Drying chamber	Stainless steel lagged with 80mm fibre glass
4	2	Parabolic collector absorber	Glass
5	1	Parabolic collector	Wooden exterior coated with stones
6	3	Tray	Perforated steel sheet guided with 3/4in x3/4in pipe
7	1	Tyre	Swivel type
8	1	Drying chamber stand	Angle iron 50mm x 50mm x 5mm
9	2	Door hinge	Stainless steel
10	1	Flat plate collector	Stainless steel
11	1	Drying chamber absorber	Glass
12	1	Flat plate collector absorber	Stainless steel
13	1	Air hose	Synthetic rubber with fibre internal lining
14	1	Blower fan	Electric fan
15	18	AS 1427 - M10 x 25	ISO metric machine screws
16	1	Valve	Stainless steel
17	1	Exhaust	Stainless steel

Fig 2: Isometric and Exploded Views of the Components of the Dryer

Thermal storage chamber

The thermal storage chamber (Figure 3) basically consists of a parabolic-shaped black plate, two end plates, a transparent cover and a receiver (absorber plate having black painted gravel under it where the incident heat is collected and stored). These parts are coupled together and the arrangement is supported by four angle irons that serve as the equipment stand.

Mode of Operation of the Dryer

The mode of operation of the dryer at daytime and night are shown in Figures 4 and 5 respectively. During the day, the source of heat energy used to dry the grains are direct heating by the solar radiation on the drying chamber and convective heating by the heated air from the flat plate collector. The fan in the air duct ensured that the heated air is properly circulated around the drying chamber for uniform drying across the trays in the drying chamber. At night, when there is no solar radiation from the sun, the source of energy is the heat energy collected and conserved in the energy storage chamber. A control valve located at the exit of the chamber is closed and opened during daytime and at night respectively to ensure continuous operation of the dryer. The combined operation of the dryer during day and night times is shown in Figure 6.

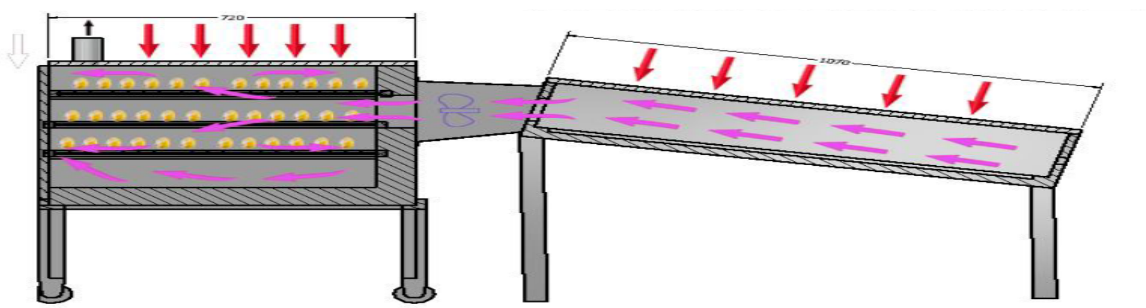


Figure 4 : Diagram showing the heat source and airflow direction in the dryer at daytime

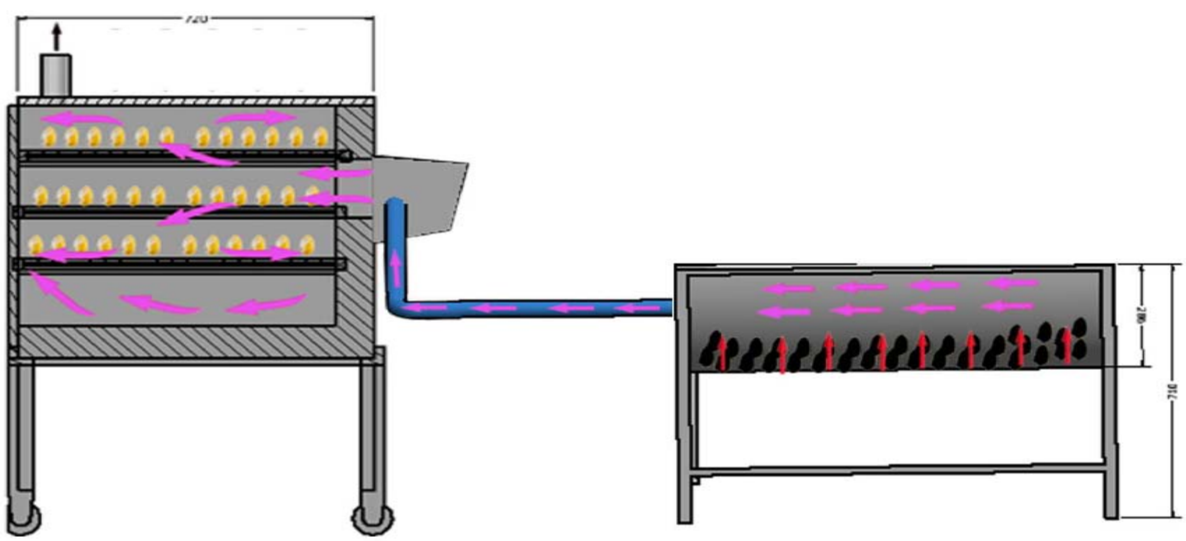
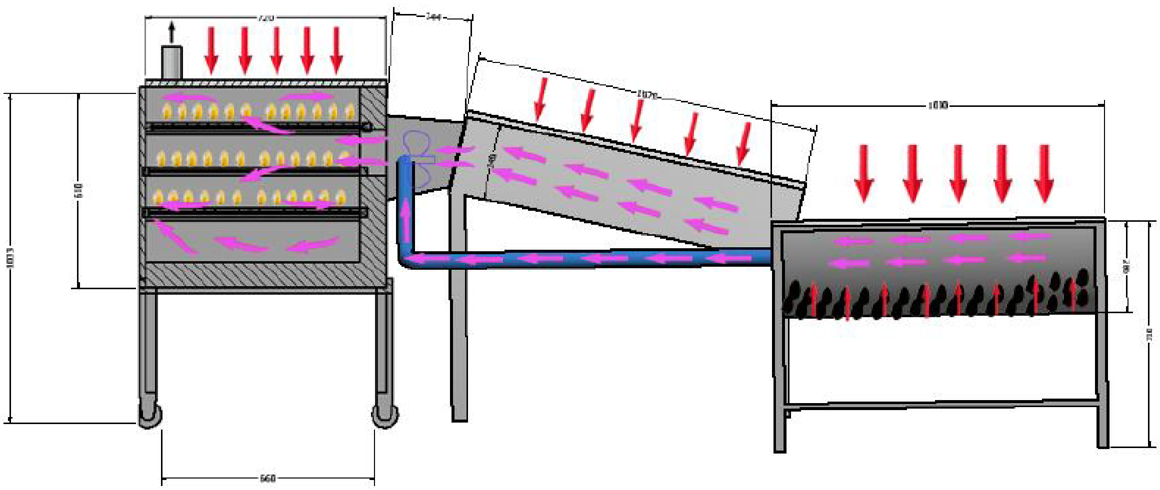


Figure 5 : Diagram showing the heat source and airflow direction inside the dryer at night



 **shows the direction of heat source**

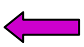
 **shows the direction of the air flow**

Fig 6: Diagram showing the combined heat sources and airflow direction inside the dryer during daytime and at night

No Load Test at Night

The test was conducted outside the Laboratory and Machine Workshops of the Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. At night, the three collectors – flat plate collector, parabolic collector and heat storage chamber – were covered with a tarpaulin and the internal temperature of these three components were recorded when the solar dryer was subjected to four combinations of valve position and collector condition; when the heat storage valve is opened and collectors were covered, when the heat storage valve is opened and collectors were uncovered, when the heat storage valve is closed and the collectors were covered and when the heat storage valve is closed and the collectors were uncovered. The internal temperatures of the three components of the dryer were measured using a thermo-anenometer (K-type, LM 8010, Lutron Instrument).

Load Test at Night

Five selected grains (cowpea, soyabean, groundnut, sorghum and maize) were obtained from the Teaching and Research Farm of the Obafemi Awolowo University, Ile-Ife, Nigeria. Prior to the drying test at daytime, the initial moisture content of each grains was determined using the oven drying method according to ASABE standard as described by Aregbesola, *et al*, (2012) sorghum, Taraghi, *et al*, (2011) for maize, ASI, (2012) for groundnut and Ajibola, *et al*, (2003) for cowpea and soyabean. 3 kg of each of the selected grains at an initial moisture content of 30% w.b were placed on the three trays inside the solar dryer and allowed to dry at 0.94 m/s. It is expected that there will be an effect of varying climatic conditions on the drying rate of the samples, thought the five samples were dried at closely similar atmospheric conditions to minimize this effect. The range of airspeed, relative humidity and ambient air temperature around the dryer during the test were (0.4 – 0.6 m/s), (80% - 90%) and 24^{o}C - 27^{o}C) respectively. At night, the fan was switched off to prevent loss of heat from the dryer. The moisture content of the grains drying each drying run was determined hourly by using a portable digital moisture meter (MC 7825G). Moisture contents reading of the sample were taken by inserting the probe of the moisture meter into the sample batch before the drying test so as to avoid heat loss from the during opening and closing of dryer for sample collection and testing.

The solar radiation during the drying period was measured using global radiation meter (GRM 100). The airspeed, relative humidity and ambient temperature of the prevailing air near the dryer were measured using a thermo-anenometer (K-type, LM 8010, Lutron Instrument). The temperatures of the plates inside the collectors were measured with a thermocouple thermometer (K-type, XMTA-7000 TAIFA®).

Results and Discussions

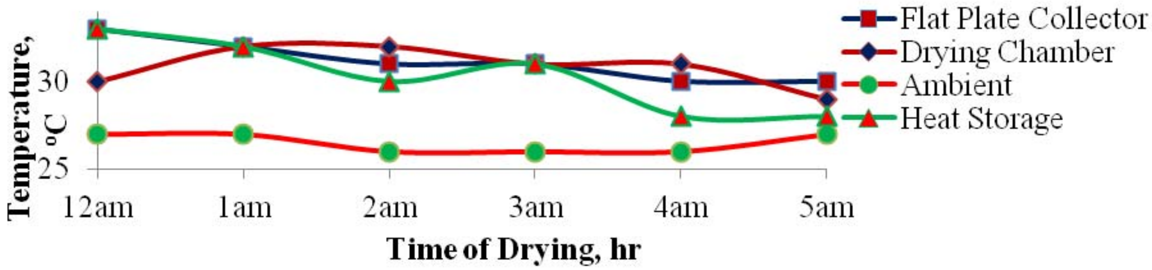
The variation in the internal temperatures of the various components of the solar dryer (flat plate collector, drying chamber, heat storage chamber) with respect to the ambient at night using the four combinations of valve position and collectors' condition are shown in Figure 7 (a-d) and discussed as below:

Effect of Collectors' Covering and Heat from Storage Chamber on the Internal Temperature of Flat Plate Collector at Night

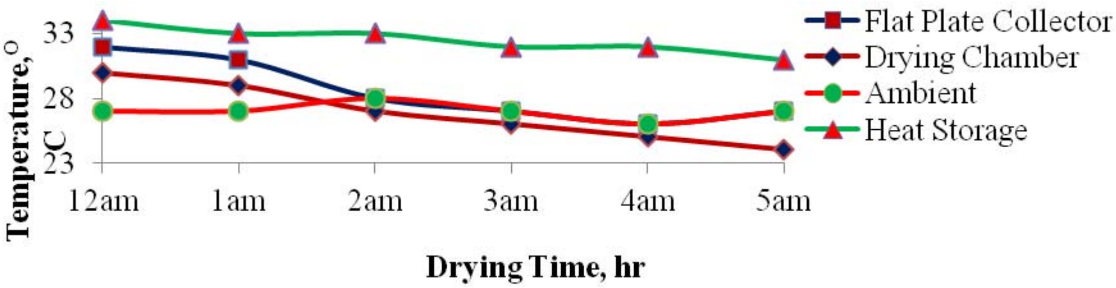
The curves show that the highest temperature (33^0C) was attained on the flat plate collector when the surface was covered and the energy storage chamber was closed at 5am whilst the least internal temperature (26^0C) was achieved when the collector was uncovered and the energy storage chamber was closed at 5am. The low temperature recorded at this time was due to loss of heat energy from the surface of the collector. It may also be due to condensation of moisture on the outer part of the collector, which in turn tends to lower the internal temperature of the collector after sometime with pronounced effect observed when dew start falling early in the morning (5am).

Effect of Collectors' Covering and Heat from Storage Chamber on the Internal Temperature of the Drying Chamber at Night

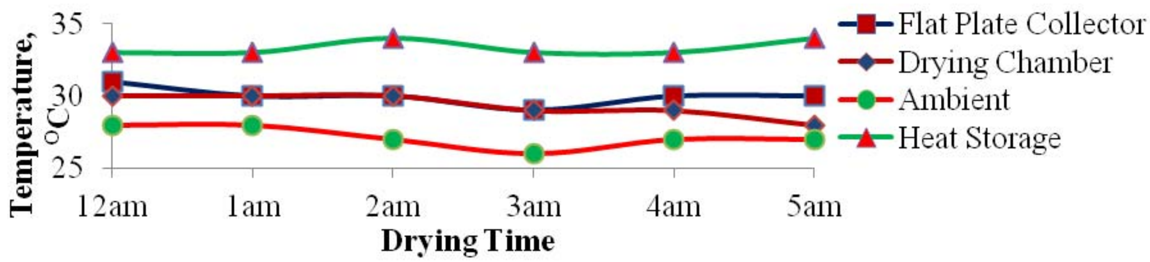
Similarly, Figures 7(a-d) show that a maximum temperature of 32^0C was attained inside the drying chamber when the collector was covered and the energy storage chamber was opened.



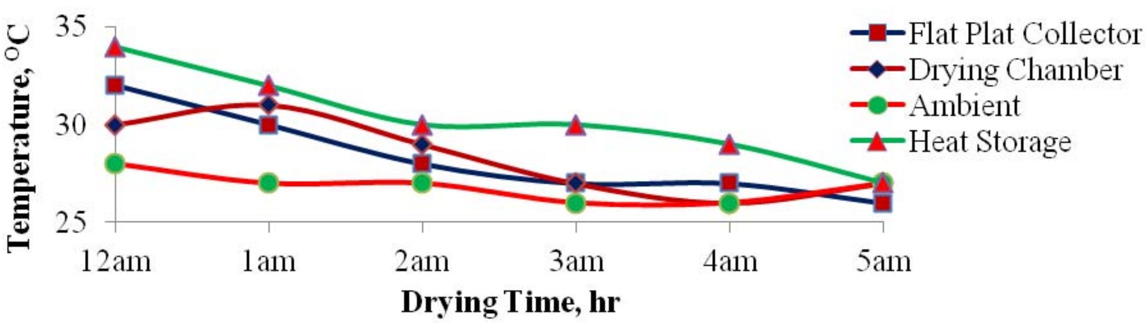
(a)



(b)



(c)



(d)

Fig 7: Temperature of solar dryer parts when (a) collector covered and valve opened (b) collector covered and valve closed (c) collector uncovered and valve opened (d) collector uncovered and valve closed at night

The reason for the high temperature when the dryer was subjected to these conditions compared to others was as a result of the insulating effect of the tarpaulin cover and the heat supplied from the energy storage chamber into the drying chamber, both of which ensured that heat is retained within the drying chamber. On the contrary, the least temperature was recorded when the collector was covered and the heat storage chamber was closed. The low temperature recorded during this condition was as a result of the condensed moisture on the outer part of the collector, resulting in reduction in the internal temperature of the heat storage chamber. Analysis of means and differences shows that there was no significant difference in the internal temperatures of the drying chamber when subjected to the four different combinations of factors (collector covering and heat energy from the heat storage chamber) except when the collectors were uncovered and valve was closed which was significantly different from others at ($P<0.05$). From this result, it shows that both the tarpaulin used to covered the collectors and the heat supplied into the drying chamber at night are important at least to prevent moisture re-absorption into chamber. This is evident in the temperature recorded at 5am when the collectors are uncovered and valve closed. There is high possibility of moisture re-absorption when the dryer is subjected to these conditions. Also, Figure 7 (a) shows that heat temperature of the heat storage chamber increased between 2 am to 3 am. This increase was due to void spaces around the gravel inside the heat storage chamber leading to heat build up at particular region in the storage chamber. The heat builds up caused an unexpected increase in temperature within storage chamber during this period. However, after some time, there is heat re-distribution in the chamber, such that is no temperature gradient in the chamber Internal temperature becomes normalized and this unusual localized temperature differences within the chamber is removed thus, ensuring that the temperature of the storage chamber decreases as expected. Similar increase in heat storage chamber was observed in Fig 7c, when the collector is uncovered and the valve is opened. There was no increase in temperature when the collector is uncovered and valve closed during these periods. What was observed was a constant temperature of 30^oC that was maintain before decrease in temperature of the heat storage chamber.

Moisture Content of Grains at During Load Test at Night

The variation in moisture contents with time of the five selected grains dried using the solar dryer at night is shown in Figure 8. There were slight reductions in the moisture content between 12 midnight and 5am in the morning, with the highest moisture drop of 4% recorded

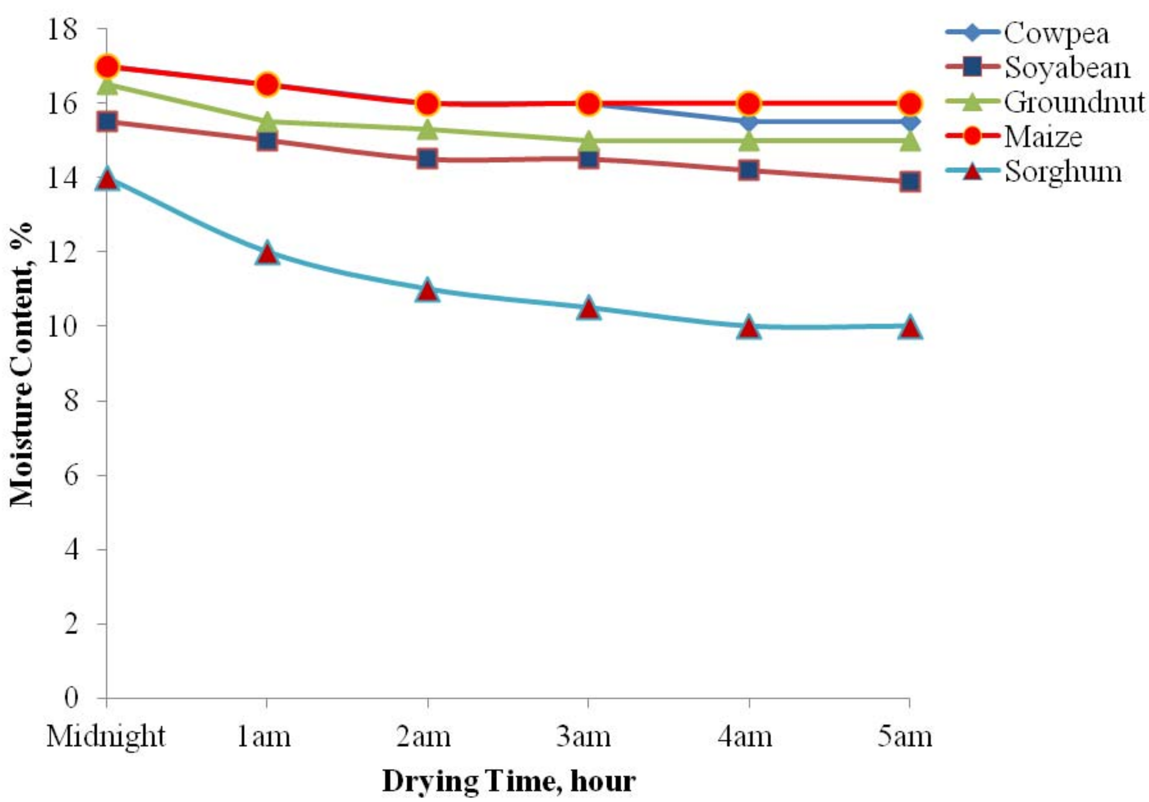


Figure 8: Variation in Moisture Content of Grains Using the Solar Dryer at Night

during drying of sorghum. The reason for this high value was due to the small size of the grains that required less energy for drying compared to other grains that are larger in sizes. The least moisture drop of 1% was recorded when drying maize. The small drop in moisture content of maize was due to the structural and molecular compositions of maize grain which consist of fibrous and cellulose materials that required more energy than smaller grains. However, for all the grains the differences in moisture contents of grains between midnight and at 5am were higher than 1%. Implying that there was moisture reduction during this period, which indicates continuous drying at night, thus it is proceed at a very slow rate but at least it evitable that there was no case of moisture re-absorption recorded at night during drying of any of the grains.

Conclusion

i. It can be concluded from this work that covering the surface of solar collectors and opening heat storage chamber increase the internal temperature inside the drying chamber. This ensures continuous drying of smaller grains (sorghum) and at least prevents moisture re-absorption during drying of large grains at night. Generally the no-load test show that the performance of the dryer is better with the energy storage chamber than without the energy storage chamber.

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