Design, Construction and Testing of Simple Solar Maize Dryer

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Abstract

This project reports the design, construction and testing of a simple solar maize dryer. It is design 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 made up of an insulating material (polystyrene) of size 100mmx50mmx25.4mm, absorber plate (aluminium) sheet painted black of size 100mmx50mm and a cover glass (5mm thickness) measuring 100mmx50mm all arranged in this order contributed to the heating. 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 9hours each day of drying.

Keywords

Solar Energy, Radiation, Airflow, Collector, Absorber Plate, Glass, Maize.

Introduction

Maize (zea-mays) falls into the cereal group of food crops, used for food by both human being and animals. At harvest, maize usually contains too much moisture (about 20%-25%) which is a favourable environment for the growth of moulds (fungi) and insects that normally cause grain damage. In order to avoid this, drying of the maize must be done to reduce the moisture content to about (11.8%-13%) for safe year-round storage.

A survey was carried out on ordinary sun drying method and it was found out that the existing method was very tedious, time wasting, wastage, in terms of produce and consequently having a very low hygienic level.

The direct exposure to sunlight, or more precisely ultraviolet radiation, can greatly reduce the level of nutrients such as vitamins in the dried product.

As a solution to these problems enumerated above, an idea was conceived and a Distribution Passive Solar Energy Maize Dryer was designed, fabricated, and tested.

The aim of this research work therefore, is to design, construct and test a Simple Solar Maize Dryer to dry at least 50kg of maize.

The design consists of two major sections made in one unit:
a. the flat collector upon which solar energy of about $400W/m^2$ is incident, transmitted and absorbed to heat air which is passed by natural convection to the drying chamber;
b. the drying chamber which contains the grains being dried.

The air having passed over the grains becomes saturated with water and is discharged through the chimney to avoid condensation of water vapour in the event that the system temperature falls (ANON 1965, 1978c)

Material and Method

The solar dryer considered in this research paper is the Distributed Passive Solar Dryer (DPSD) or Hybrid Dryer (HD). Here the product is located on trays or shelves inside an opaque drying chamber. Solar radiation is thus not incident directly on the crop. Preheated air warmed during its flow through a low-pressure thermos phonic solar energy air heater, is ducted to the drying chamber to dry the product. Because the products are not subjected to direct sunshine, Localized heat damage, do not occur. A typical Distributed Passive Solar Energy Dryer is made up of the following basic units:

(a)A Drying chamber.
(b)An air-heating solar energy collector, which consists of cover plate, absorber plate and insulator.

Drying Chamber

The drying chambers made of a highly polished plywood box held in place by angle irons. The material has been chosen since wood is a poor conductor of heat and its has smooth surface finish; heat loss by radiation is minimized.

To further reduce heat loss by radiation and to avoid moisture absorption by the wood, aluminium foil is wrapped on the inside of the chamber.

Cover Plate

This is transparent sheet used to cover the absorber, thereby preventing dust and rain from coming in contact with the absorber. It also retards the heat from escaping (i.e. forming a confinement for heated air) It is placed about 25.4mm above the absorber. Common materials used for cover plates are glass, flexi glass, fibreglass, reinforced polyester, thin plastic films and plastics.

Absorber Plate

This is a metal plate painted black and placed about 25.4mm below the cover to absorb the incident solar radiation transmitted by the cover thereby heating the air between it and the cover. In its plainest form, it is no more than a blackened metal plate exposed to the sun.

Insulator

This is used to minimize heat loss from the system. It is placed under the absorber plate. The insulator must be able to withstand stagnation temperature, should be fire resistant and not subject to out-going gassing; and should not be damageable by moisture or insect. Insulating materials are usually fibreglass, mineral wool, Styrofoam and urethanes.

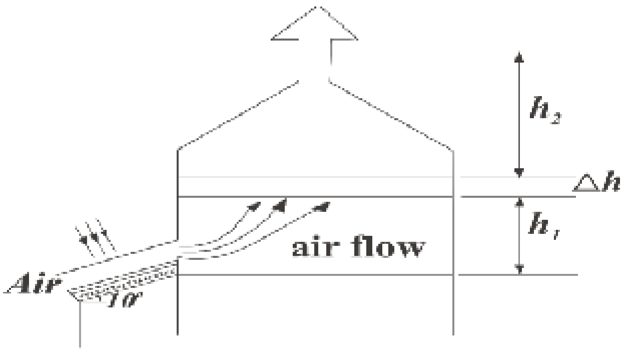

***Figure 1**. Representation of the Solar Maize Dryer*

Design specification

Average mass of each maize = 0.4kg

Number of maize = 125cobs

Total mass of maize = 125x0.4 =50kg

Drying period required =9hrsx3days =27hrs

Density of maize = 824kg/m^3

Moisture content of maize at harvest = 20%

Expected moisture content after drying = 13%

Average ambient temperature (Ta) = 27^{o}C(300K)

Relative humidity (RH) = 80%

Height below bed of the dryer (h_1) = 0.2m

Height above bed of the dryer (h_2) = 0.4m

Atmospheric pressure = 101.3kpa

Gravitational acceleration (g) =9.81m/s

Temperature of air below the bed (Tp) = 44^{o}C(317K)

Temperature of air above the bed (Ts) = 32^{O}C(305K)

Characteristic gas constant, R = 0.287Kj/KgK

$$\Delta P = \{h1\ (\rho - \rho_1) + h_2\ (\rho - \rho_2)\}\ g \quad (1)$$

$$P = \rho RT \Rightarrow \rho = P/\ RT \quad (2)$$

$$\Rightarrow \rho = 101.3/\ 0.287x300 = 1.177\ Kg/m^3$$

$$\Rightarrow \rho_1 = 101.3\ /\ \{0.287x317) = 1.113\ Kg/\ m^3$$

$$\Rightarrow \rho_2 = 101.3/\ \{0.287x305) = 1.157\ Kg/\ m^3$$

Therefore, the pressure drop across the bed is

ΔP = {0.2(1.177-1.113) +0.4 (1.177-1.157)} 9.81 = 0.204N/m^2

Mass of moisture removed per 50Kg of wet maize

Mm =_m (wt%-dry %) /{100% - dry%) (3)

= 50(0.2- 0.13) / {1 – 0.13) = 4.02Kg

From psychometric chart, the humidity ratio increases from 0.018Kg to 0.024Kg per Kg of dry air.

Mair = mass of moisture to be removed / Increase in humidity ratio\ (4)

= 4.02(0.024 – 0.018) = 670Kg

The air mass flow rate Mair = 670 / (27x60min) =0.414Kg/min

$\Delta P = Mair\ \Delta h / K\ \rho\ Ad$ (5)

$0.204 = 0.414x\Delta h / (0.1x1.177xAd)$

$\Delta h / Ad = 0.058m^{-1}$

Volume of maize = Mass of maize / Density of maize = $\Delta h\ Ad$ (6)

$\Delta\ h\ Ad = 50 / 824 = 0.061m^2$

$\Delta h\ \Delta h\ Ad / Ad = (\Delta h)^2 = 0.058x0.061 = 3.538X10^{-3}m^2$

$\Delta h = (3.538x10^{-3})^{1/2} = 0.0595 \approx 0.06m$

Ad = Volume / Height of bed = $\Delta h\ Ad / \Delta h$

$=0.061/ 0.06 = 1.02m^2 \approx 1m^2$

Bed of maize = 1mx1mx0.06m

Where

ΔP – pressure drop across the bed (N/m^2)

ρ– air density outside the dryer (Kg/ m^3)

ρ_1- air density below bed (Kg/ m^3)

ρ_2- air density above bed (Kg/ m^3)

M_m- mass of moisture removed (Kg)

M_{air}- mass of dry air required (Kg)

Δh –height of the maize bed (m)

Ad –area of the maize bed (m)

An-air heating solar energy collector design

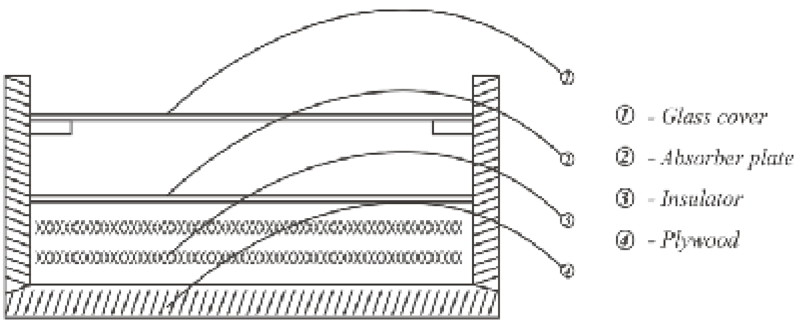

***Figure 2**. Representation of Solar Collector*

$Qu = Ac\,(It\tau\alpha - U_L\,(Tp - Ta))\,F_R$ (Exell, 1980) (7)

$Q = M_L + Mh_{fg}$ (8)

For this design

Ac – area of collector (m^2)

It – solar energy received on the upper surface = 375w/m^2

U_L – heat coefficient =7.38w/m^{2o}C

$\tau\alpha$ – transmissivity = 0.89(n)

Qu – useful heat energy (w)

F_R – heat removed factor of collector depending on the material = 0.9

Tp – average temperature of air below the bed 44^{o}C

Ts –average temperature of air above the bed 32^{0}C.

Ta –average ambient temperature 27^{o}C

Q –heat required to remove m (Kg) of moisture (Mj)

M –mass of moisture (Kg)

L –latent heat of evaporation from steam table = 2.26x10^6J/Kg

H_{fg}–from steam table = 43990 Kj/Kmol of H_2O

T –total drying period = (27hoursx3600) sec

From (8) above Q_1 = 4x2.26X10^6 + 4x43990 = 9.2MJ

Q_2 = 9.2x10^6 / 27x3600 = 94.65w

From (7) above

4.65 =Acx0.9 (375x0.89 – 7.38(44-27))

Ac = 94.65 / 187.46 = 0.504m^2 ≈ 0.50m^2

Collector size = L (m) x 0.50 (m)

Collector tilt is approximately equal to the latitude of the location, for this design ϴ = 10^o (ANON 1978a)

Distance between the glass cover and absorber plate is approximately 25.4mm for proper heating of the in flow air (ANON 1978a, 1978b).

Testing

The testing of the solar maize dryer was done in the month of August for three days. The solar Dryer was placed outside with the collector facing the direction of the sun. The collector has been rigidly fixed to the dryer at an angle approximately 10^o to the horizontal to obtain approximately perpendicular beam of sun rays to avoid damage in transit. About 125 cobs of freshly harvested maize estimated to weigh averagely 0.4kg each (total mass of maize=50kg) were arranged on the drying bed in a single layer to avoid moisture being trapped in the lower layer. The dryer chamber door was closed and seals placed in position. The result obtained for hourly reading of 9hours everyday is tabulated in tables 1-3.

Results

Result on 6th August 2007.

Table1. Variation of Temperature with Time on the First day.

Day1										
Time	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm
Ts(^{0}C)	31	33	35	36	36.5	32	32	37	38	38
Tp(^{0}C)	48	51	49	50	54	49	45	56	50	45
M(Kg)	50									48.2

Ma-mass of maize at 9:00 am, Mb-mass of maize at 6:00pm

Moisture removed =Ma-Mb =50-48.2 =1.8kg

Results on 7th August 2007

Table 2: Variation of Temperature with Time on the Second day.

Day2										
Time	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm
Ts(^{0}C)	30	33	35	35.5	35	37	37	36	36.5	37
Tp(^{0}C)	46	45	48	50	49	52	51	47	56	55
M(Kg)	48.2									47.2

Ma = 48.2kg, Mb = 47.0kg, Moisture removed = 48.2-47.2 =1.0kg

Results on 8th August 2007

Table 3: Variation of Temperature with Time on the Third day.

Day3										
Time	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm
Ts(^{0}C)	26	30	32	36	36	37	36	36	35	35
Tp(^{0}C)	40	50	59	60	63	59	53	52	48	44
M(Kg)	47.2									46.2

Ma =47.2kg, Mb =46.3kg, Moisture removed =47.2-46.3 =0.9kg.

Discussion of Results

Based on the results obtained during the test of dryer, temperature above 45^{o}C was recorded against the ambient temperature in the drying chamber. Large quantity of moisture 1.8kg was removed on the first day because the skin of the maize was soft and it was easy for evaporation to take place. As the maize dried, the skin became harder and rate of evaporation reduced, so quantity of moisture removed on the third day reduced to 0.9kg. Tables 1 to 3 show the variation of inside temperature of the drying chamber with respect to time.

Conclusions

In conclusion, the need for the construction of a solar dryer arose as an alternative to ordinary sun-drying technique.

Based on the results obtained during the test, temperature above 45^{o}C was recorded. This high temperature in the drying chamber causes 1.8kg of moisture to be removed on the first day, 1.0kg on the second day and 0.9kg on the third day. At the end of the third day, the mass of 50kg of maize was reduced to 46.3kg. Total amount of moisture removed was 3.7kg, which is the required amount of moisture to be removed for safe storage of maize.

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