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Grain (Maize) Solar Dryer

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Abstract— *A solar dryer used for agricultural produce has been developed. Major components of the dryer include: (i) flat plate collector, (ii) glass cover (iii) drying chamber, and (iv) lagging material. The flat plate collector was made with corrugated iron sheet coated dull black. The absorber is insulated with 50mm thick fibre glass. The solar collector has a surface area of 0.315m^2, mounted on a frame tilted to an angle of 45 degrees. Performance test showed that the dryer recorded a maximum temperature of 66^{0}C at an average heat gain of 9176.06KJ.*
Keywords— absorber, drying, heat, insulation and solar

I. INTRODUCTION

Solar Dryer has been developed for drying of agricultural produce in order to improve self-life (Esper and Muhlbauer, 1996). However, for a large scale production the limitation of open air drying is well known. Among these are:

a) Large drying area requirement.
b) High labour cost.
c) Inability to control the drying process.
d) Possible degradation due to biochemical and microbiological reactions.
e) Insect infestation etc.

In order to benefit from the free and renewable energy source provided by the sun, numerous attempts have been made. This gave rise to the development in recent years of simple solar drying system mainly for drying agricultural and forest produce.

1.1 The advantages of solar drying are these:

a) Non-polluting source of energy.
b) Renewable energy.
c) Cheapness of energy.
d) Abundant non-monopolized energy source.

The project is aimed at producing a small-scale solar dryer comprising of three parts- the collector, the control gate and the drying chamber that are constructed using locally available materials such as wood, metal/non-metal etc. to a standard design configuration.

The solar dryer offers advantages over the open-air drying in that, it is a much more efficient drying method following with minimal wastage and spoilage.

The constructed dryer in this project can be adapted in the drying of other produce such as fruits and vegetables.

II. OPERATIONAL PRINCIPLE

The dryer consists of a flat plate collector made of corrugated iron sheet measuring (900mm x 350mm) coated with dull black paint and a glass cover measuring (900mm x 360mm) was used as top cover. The drying chamber measuring (250 x 520 x 560) fabricated with wood and partitioned into four sections. The absorber is made up of wood, corrugated iron sheet coated black, Aluminium foil and lagging materials.

The three sections of the drying storage houses the maize cobs for drying and the fourth is filled with stone painted black to serve as reservoir. When this device is exposed to the sun, the sun's incident radiation which enters the collector is being trapped by the absorber and by means of natural convection heats up the air which entered the heating zone; this air enters the drying compartment fully heated, extracts the moisture from the maize and is being exhausted through the chimney.

III. DESIGN ANALYSIS

3.1 Assumptions

- Average mass of each maize cob = 0.4kg
- Number of maize cobs =125
- Density of maize = 824kg/m^3 (Joshua Folaranmi, FUTmina)
- Moisture content of maize at harvest X_i = 20%
- Expected moisture content after drying X_f =13%
- Average monthly ambient air temperature of owerri obtained from FUTO metrological centre = 30°C
- Average relative humidity of Owerri = 74% (FUTO metrological centre).
- Specific heat capacity of water at 56 °C= 4.178KJKg^{-1}k^{-1}
- Total mass of maize = 125 x 0.4 =50kg
- Mass of moisture content of maize at harvest M_i =20/100 x 50/1 = 10kg
- Mass of moisture content after drying = 13/100 x 50/1 =6.5kg
- Mass of moisture content to be removed = 10 – 6.5 =3.5kg
- Mass of maize at final moisture content X_f (13%) = 50 – 3.5 = 46.5kg

- The volume of maize to be dried:

Volume (V) = Mass (M) / Density (D) (Okeke, 1998)
Thus, V = $50kg/824kgm^{-3} = 0.0607m^3$
The volume of the dryer should not be less than $0.07m^3$ internally.
The dryer has a volume capacity of height = 52cm, length = 56cm and width = 25cm.
Hence, Volume = 52 x 56 x 25 = $0.0728m^3$ with this, the design is safe.

3.2 Measured Parameter

Thermal conductivity of glass, K_g = 385 W/mK
Thermal conductivity of absorber plate, K_a = 225 W/mK (Rajput, 2002)
Thermal conductivity of insulating material, K_i = 0.04 W/mK
Insolation = $430W/m^2$
Number of cover material (glazing), n = 1 (Rajput, 2002)
Transmittance of the cover material, ε = 0.9
Absorptivity of the absorber plate (coated with black enamel paint), φ= 0.89 (Rajput, 2002)

3.3 Flat Collector

Area of the collector

$$, A = l \times w = 0.9 \times 0.35 = 0.315m^2$$

3.4 Glass Cover Collector

Area of the collector $= l \times w = 0.9 \times 0.36 = 0.324m^2$

3.5 Drying Chamber

volume of the drying chamber, $V = l \times w \times h = 0.250 \times 0.520 \times 0.560 = 0.0728m^3$

3.6 Heat Load Calculation

To do this, the approach used by Agorua (1991) was followed.
The heating load is defined as the quantity of heat required to dry the fixed quantity of maize from 20% to 13% moisture content. It is the sum of:

1) Heat load required to evaporate the water content of the maize, which is 3.5kg of water denoted by Q_1.
2) The heat required to heat the maize from 30 °C ambient
Temperature to 56^oC or sensible heating load denoted by Q_2
3) The heat lost without being utilized by the dryer, denoted by Q_3

Thus,

$$Q(kj) = Q_1 + Q_2 + Q_3 \text{Type equation here.}$$

3.6.1 The Evaporative Load (Q_1)

$$\frac{Q_1}{M_w} = \Delta H$$

Where M_w = mass of water to be removed = 3.5kg
ΔH = mean enthalpy required evaporating a unit mass of water it is given as:

$$\Delta H = \Delta H_v + \Delta H_w$$

ΔH_v = Latent heat of vaporization in $KJkg^{-1}k^{-1}$

ΔH_w = Enthalpy of wetting in $Kjkg^{-1}$

For the case of maize with a little high hydroscopic value, an average of 1.5% was chosen. The enthalpy of wetting becomes:

$\Delta H_w = \Delta H_v$ (0.015)

The latent heat of vaporization of water at 56°C = 2343.1 $KJKg^{-1}$(from the steam table)

Thus, $\Delta H = \Delta H_v + \Delta H_v$ (0.015)

$= \Delta H_v$ (1.015)
= 2343.1 x 1.015
= $2378.25KJKg^{-1}$

The evaporative load, from equation above now becomes

$Q_1 = M_w \times \Delta H$
= 3.5 x 2378.25
= 8323.88KJ

3.6.2 The Sensible Heating Load (Q_2)

The enthalpy per unit mass of dry maize is given by:

$\Delta h = (C_{pw}\Delta T - \Delta H_w) (X_i – X_f)$

ΔT = (56 – 30) = Temperature difference between the drying air temperature and the initial temperature of maize.

From equation $\Delta H_w = \Delta H - \Delta H_v$
= 2378.25 – 2343.1 = $35.15KJKg^{-1}$
C_{pw} = 4.178 $KJKg\text{-}^1K^{-1}$, X_i = 20%, X_f = 13%

Hence, Δh = [(4.178) (56 -30) – 35. 15] [0.2 – 0.13]
= $5.14KJKg^{-1}$

Total sensible heating load: $Q_2 = \Delta h\ M_w$ = 5.14 x3.5== 17.99KJ

3.6.3 The Heat Losses (Q_3)

This accounts for the heat losses from the walls and roof of the drying chamber to the surrounding end from the collector outlet channel. A good dryer design will not allow more than 8 – 12% of the latent heat of vaporization and the sensible heat load to be lost as heat losses. Therefore we assume 10% heat was lost.

$Q_3 = 0.10 \times (Q_1+Q_2)$
= 0.10 x (8323.88 + 17.99)
= 834.19KJ

Therefore the total heating load required
Q = 8323.88 + 17.99 + 834.19
= 9176.06KJ
Thus the quantity of heat expected from this design is 9176.06KJ

3.7 Materials for Construction

Corrugated iron was used for the solar collector since it is comparatively cheaper and has a high thermal conductivity. It has lightweight and a good material for the solar absorber. It is coated with black enamel paint for higher performance (Marcus, 1999). Black paint has the ability to absorb light of virtually all wavelengths (Daniels, 1977).White glass was used for the cover plate for its stability and high transmittance to visible light (Hii, 2012). It also has low transmittance to infra-red radiations (Green, 2001). Fibre glass was used for insulation. It is comparatively cheaper and readily available. It is widely used for its low thermal conductivity.

IV. PERFORMANCE EVALUATION

4.1 Parameter Measured

Inlet temperature to collector, T_{ci}

Outlet temperature from collector, T_{co}.

Outlet temperature from drying, T_{do}

Ambient temperature, Ta = 30°C

Cover plate temperature, T_c

Absorber plate temperature, T_p

Absorber plate temperature with stone (T_{psc}) collector

Time of smoke reaching collector outlet, t_c

Absorber stone temperature in the drying chamber, T_s

Total time for smoke to travel from collector inlet to chimney exist, t_t

Time for smoke to travel from inlet to drying chamber to chimney outlet, t_o

Assumed maximum temperature of absorber plate, T_P = 100 °C

Overall Heat Transfer Coefficient, $U_o = Q_l / (T_p - T_a)$
= (0.4 x 430) / (100 -30) = 2.45W/m²°C.

Efficiency of the collector, (%) = 100 x $(T_2 - T_1) / T_p$

$$= 59.5 - 30/_{100} = 0.295$$

V. RESULTS

Table 1: Temperature and time as obtained on 15th Jan. 2015.

Time of day	T_C (°C)	T_P (°C)	T_{Ci} (°c)	T_{CO} (°c)	T_{do} (°c)	T_a(°c)	T_c (s)	T_t (s)	T_d (S)	T_{PS} (°c)	T_S (°c)
12:00 pm	50	62	36	58	59	30	-	-	-	74	64
1:00pm	50	67	38	61	58	30	4	20	16	77	66
2:00pm	46	60	35	55	55	31	-	-	-	71	60
3:00pm	49	70	38	64	66	34	5	23	18	82	75

VI. DISCUSSION

Maximum recorded efficiency of the dryer = 29.5%
Maximum output temperature = 66°C.
The ideal maximum efficiency of a dryer is 100% but this dryer gave maximum efficiency of 29.5%. This is due to number of factors such as weather condition, insulation and design factor. Further improvement in these factors will as well improve the drying efficiency.

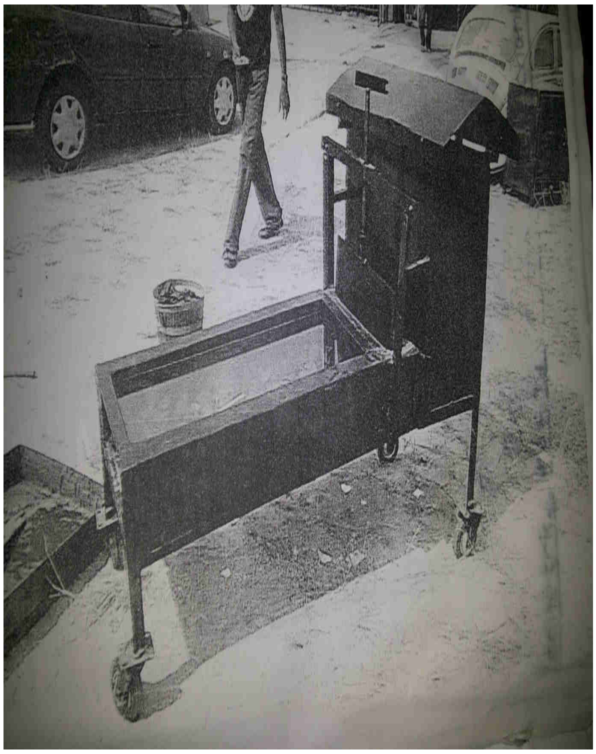

Fig 1 Picture of Solar Grain (Maize) Dryer

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