Design and Construction of Hybrid Dryer for Grains

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ORIGINAL RESEARCH

Abstract— The demand for an efficient drying method among farmers has increased due to the need to reduce substantial losses resulting from inadequate drying facilities. Most imported dryers are too expensive and not accessible to small-scale farmers. Traditional methods like sun drying and solar dryers are limited to daytime use and depend on solar irradiation and weather conditions, including cloud cover, relative humidity, and wind speed. Therefore, there is an urgent need for a locally developed grain dryer. A prototype hybrid grain dryer was carefully designed, fabricated, and assembled at the Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria. Its components include an axial fan, solar collector, heating chamber, air duct, drying tray, drying chamber, and frame. The dryer was evaluated with maize grain and showed impressive sensible heat utilization efficiency and drying efficiency of (55.9%, 65.6%, 68.0%) and (27.7%, 29.9%, 32.8%) across air flow rate of 3.6, 4.5 and 6.1 m^3/s and (53.0%, 63.1%, 73.5%) and (23.2%, 29.8%, 37.3%) across grain depths of 5, 10, 20cm respectively.

Keywords— Sun drying, hybrid grain dryer, Postharvest lost, Maize grain, Efficiency.

1 INTRODUCTION

Agricultural processing involves various operations such as pre-drying, threshing, pre-cleaning, drying, cleaning, sorting, and packaging. These operations are carried out to maintain and enhance the quality of agricultural products, or to alter their form or characteristics. The primary goal of agricultural processing is to minimize any deterioration in the quality and quantity of the material after it has been harvested (Sahay and Singh, 2005). Drying is one of the oldest methods of food preservation known to man (Sobukola et al., 2007). It involves removing water to a safe level to reduce product deterioration, provide microbiological stability, and extend the life of the products (Perumal, 2007). This process substantially reduces weight and volume, minimizes packaging, storage, and transportation costs (Sagar and Suresh, 2010). By reducing the moisture content of food material to between 10-20%, the actions of bacteria, yeast, molds, and enzymes are drastically reduced (Nandi, 2009). Since microorganisms are the primary cause of food spoilage and water (moisture) is essential to their growth, it's important to remove the water to a safe level. Drying preserves and concentrates the flavor and most of the dried product's nutritional contents (Herringshaw, 1997). Additionally, dried products do not require any special storage facility or equipment and are easy to handle and transport (Scalin, 1997).

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Section A- AGRICULTURAL ENGINEERING & RELATED SCIENCES

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In Nigeria, agricultural produce is mainly dried using open-air drying or sun-drying, with limited use of mechanical dryers or other methods. Open-air drying is the oldest, cheapest, and most widely used option, and is practiced in many parts of the world, including Nigeria. Mechanized drying, on the other hand, is mainly used in industrialized sectors. It involves using boilers to heat incoming air and fans to force air through at a high rate (Ajay *et al.*, 2009).

Ajay *et al.* (2009) reported that solar dryers have been known to people long ago, however, their widespread use is restricted because of their dependency on weather. During the rainy season, local farmers are faced with the challenge(s) of drying after harvest. Early grains (corn) that are harvested amidst rainy season, and late irrigated maize harvested at the onset of the rainy season poses a great threat to farmers as losses are incurred because of lack of available dryer. The rainy season corn is harvested at the time the atmospheric humidity is usually very high and almost impossible for hygroscopic products like grains to be properly dried naturally during such a period. There is, therefore, a need for an improved means of drying. Most available imported dryers though efficient, often require electricity and skill for their operations. Most rural areas in Nigeria have no access to constant electric power to operate such machines, the machines are usually too expensive to be purchased by local farmers, rendering it unimportant as it cannot be used to solve their need. While open air drying is inexpensive and most extensively used, it entirely depends on whether conditions. It is labour intensive, unhygienic, unreliable, time consuming, non-uniform drying and requires a large area for spreading the produce to dry. Grains that are dried on bare ground are more susceptible to contamination by fungi that produce aflatoxins which is harmful to human health.

2 MATERIALS AND METHODS

The materials chosen for the dryer components were based on strength, durability, availability, and cost. We used locally sourced materials for construction. The machine frame was made from square pipe, while plywood was used for the drying chamber due to its poor heat conductivity. Aluminium sheet was chosen for its superior thermal absorptive capacity compared to other options like mild steel, zinc, and concrete surfaces. A mild steel sheet was used for the heating unit and air vent due to its ability to withstand heat and air pressure from the fan. Transparent polythene was selected as the covering material because it is cost-effective and easy to replace. We opted for a low-energy axial fan to intake ambient air into the collector. Wire mesh, angle iron, and sheet metal were used in constructing the drying tray. The dryer was constructed at the department of Agricultural and bio-resources Engineering, Ahmadu Bello University, Zaria, Nigeria.

2.1 Design Considerations

The following design criteria were taken into consideration.

i. A collector with high absorptive capacity.
ii. An efficient means of air circulation to reduce the static pressure which must be overcome to supply the desired airflow to the grains placed on the tray.
iii. A drying chamber that is a poor conductor of heat, to reduce heat lost to the surroundings.
iv. To avoid the accumulation of vapor, the upper lid of the dryer was opened, for easy flow of vapor picked by the heated air from the grains to the atmosphere.

2.2 Design Calculations

The following steps were followed in designing the various components of the dryer

2.2.1 The total amount of moisture to be removed (Mw)

This can be determined from the relationship given in equation 1 by Ampratwum (1998) as cited by Isiaka (2009):

$$m_w = \frac{M_p(m_i - m_f)}{100 - m_f} \quad (1)$$

Where:

m_w = Mass of water to be removed

M_p = initial total weight (75kg)

m_i = initial moisture content on wet basis (23%)

m_f = the final moisture content on wet basis (12%)

That means

$$m_w = \frac{75(23-12)}{100-12} = 9.375\text{kg}$$

2.2.2 Energy Required to Evaporate Available Moisture (E)

The energy required to evaporate available moisture is equivalent to the collector's useful energy gain. This was calculated according to Eke (1991) and Isiaka (2009) using the relationship as given in equation 2:

$$E = W_m CP_m (T_2 - T_1) + I_v W_1 \quad (2)$$

Where:

E= Collector useful energy gain, kJ

W_m= Weight of material to be dried

CP_m= Specific heat of material kJ/kg/℃

T_2= Temperature of air inside dryer

T_1= Ambient air temperature

I_v= Heat of vaporization

W_1= Weight of moisture to be removed

2.2.3 Determination of Useful Energy Collection Rate

This was determined using the equation 3 given by Duffie *et al.*, (1979)

$$Q_u = F_R h_e I_H A_c \quad (3)$$

Q_u= Total useful energy collection rate, KJ/h

F_R = Heat removal factor≈0.7-0.8 for air cooled collector

h_e= Effective transmittance-absorptance product ≈ 0.5 for single transparent covering

I_H= incident solar radiation, W/m² = 473W/m² within January to April for I.A.R and environs as reported by Isiaka, (2009).

2.2.4 The Mass flow rate of Air Needed for Drying

The mass flow rate of air needed for drying was obtained as given by (Forson *et al.*, 2007) in equation 4:

$$M_a = \frac{Q_u}{C_p(T_2 - T_1)} \quad (4)$$

Where:

M_a= mass flow rate, kg/hr

Q_u = Useful energy gain flow rate kJ/s

T_1 and T_2 = Ambient temperature 26℃ and Drying air temperature 55℃

C_p = Specific heat of air at T_2= 1.009 kJ/kg

2.2.5 Pressure Drop through the Drying Bed

To select a fan to adequately deliver air through a grain bed, equation 5 as given by modified Shedd equation was used:

$$\Delta p = \frac{cQ^2}{\ln(1 + dQ)} \quad (5)$$

Where:

Δp = Pressure drop, Pa/m

Q= Air flow rate, cfm

c and d are constant for a particular grain, for shelled corn as given by: Bakker-Arkema *et al.*, (1999)

2.2.6 Determination of Axial fan Power

Power requirement of an axial flow fan according to Hellenvang (2013) was obtain using the relation as given in equation 6:

$$Horsepower = \frac{Airflow\ rate(cfm) \times \Delta P}{6320 \times \eta_f} \quad (6)$$

ΔP = Pressure drop through a grain depth

η_f =Fan efficiency (decimal)

2.2.7 Quantity of Kerosene Needed for Combustion

The quantity of kerosene needed to burn in the combustion chamber was determined using the equation 7 given by Olaniyan and Alabi (2014)

$$\boldsymbol{Q_k} = \frac{Q}{C_k} \quad (7)$$

Where:

Q_k = Quantity of kerosene needed for combustion, kg

Q= Amount of heat energy required for drying, kg/s

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C_k = Calorific Value of kerosene, kJ/kg
The calorific value of kerosene is 46200kJ/kg

2.3 DESCRIPTION OF THE HYBRID SOLAR DRYER

The hybrid dryer consists of an axial fan, solar collector, heating chamber, air duct, drying tray, drying chamber, and frame. The axial fan drives ambient air into the solar collector/heating chamber, and the heated air is dispersed more effectively through the air duct. The product to be dried is placed on a drying tray within the drying chamber. Visual views of the dryer are shown in Figure 1a, while Figure 1b-1e depict the dryer's component elements.

Figure 1a: Pictorial view of the Hybrid dryer for Grain

Fig 1b: Heating Chamber

Figure 1c: Drying tray

Figure 1d: Axial fan and air duct

Figure 1e: Solar collector

2.4 PERFORMANCE INDICATOR

The performance indicators used were sensible heat

removal to total sensible heat in the drying air, it is given by: (FAO, 1994) in equation 8:

$$(\text{SHUE}) = \frac{Heat\ Utilized\ for\ Moisture\ Removal}{Total\ Sensible\ Heat\ in\ the\ Drying\ Air} \quad (8)$$

2.4.2 Drying System Efficiency (η_d)

Drying efficiency concerns how effectively a drying process eliminates moisture from a substance. It is quantified as the ratio of the energy needed to vaporize the moisture to the energy provided to the dryer. This metric gauges the comprehensive efficacy of a drying setup as shown in equation 9 given by (FAO, 1994):

$$\eta_d = \frac{M_w h_{fg}}{I A_c t} \quad (9)$$

Where:
M_w = Mass of moisture evaporated
h_{fg} = Latent heat of vaporization of water at dryer temperature (kJ/kg)
A_c = Collector surface area (m^2)
I =Insolation on collector surface (W/m^2)
t =Time taken to evaporate the moisture (s)

3.0 RESULTS AND DISCUSSION

The dryer was successfully constructed and the following instruments were employed in taking measurements. They include Digital weighing balance (Baykon BX21) with a sensitivity of 0.02kg, Digital air flow meter (Fluke flow meter 922) with a sensitivity of 0.001, Handheld wind vane (CUP Anemometer: AM-4220) with a sensitivity of 0.9-35m/s, Digital temperature and humidity meter (Smart Sensor) with a sensitivity of 1°C, ±3%, Digital Grain Moisture Probe with a sensitivity of ±5%, and a Techno stopwatch. Statistical analysis was done using SAS Version 9.0.

3.1 EFFECT OF GRAIN DEPTH ON DRYING SYSTEM EFFICIENCY

The highest mean drying efficiency of 32.8% was recorded when air flow rate of 6.1m^3/s was used as shown in table 1. The drying efficiency drops to 29.9% when air flow rate of 4.5m^3/s was used, this efficiency further drops to 27.7% when the flow rate was 3.6m^3/s, these efficiencies are numerically different but statistically the same, it can be deduced that increasing air flow rate from 4.5 to

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$6.1m^3$/s significantly affect drying efficiency, but there is no significant effect when the flow rate is increased from 3.6 to $4.5m^3$/s in thin layer drying of maize. For the drying depth, drying efficiency of 37.3% was recorded at 20cm drying depth, which is significantly higher when compared with respect to other values of 29.8 and 23.2% when grain depths of 10 and 5 cm were used, respectively. From the result, it shows that drying efficiency increases when the drying depth increases, this is because the energy in the drying air is more efficiently utilized, since the time lag for the drying air is increased.

Table 1: Effect of air flow rate and grain depth on drying efficiency

Mean Drying Efficiency (%)	
Treatments	Drying Efficiency
Air flow rate (V) (m^3/sec)	
3.6	27.7b
4.5	29.9b
6.1	32.8a
SE±	0.924
Grain depth (B) (cm)	
5	23.2c
10	29.8b
20	37.3a
SE±	0.924

NS= Not significant Mean followed by same letter(s) on the same column are not different statistically at *P=0.05* using DMRT.

3.2 Effect of Grain Depth on Sensible Heat Utilization Efficiency

From Table 2, the mean sensible heat utilization efficiency of 68.0% was recoded when air flow rate was $6.1m^3$/s and 65.6% when air flow rate $4.5m^3$/s was used and these were significantly higher compared to 55.9% sensible heat utilization efficiency when $3.6m^3$/s air flow rate was used. This implies that sensible heat utilization efficiency increases with an increase in air velocity. For the grain depth, the mean sensible heat utilization efficiency of 73.5% was recorded at 20cm grain depth, which is significantly higher when compared with other values of 63.1 and 53.0% when grain depths of 10 and 5 cm were used, respectively. From the result, heat utilized for moisture removal increases when the drying depth increases.

Table 2: Effect of air flow rate and grain depth on sensible heat utilization efficiency

Mean Sensible Heat Utilization Efficiency (%)	
Treatments	Sensible Heat Utilization Efficiency
Air flow rate (V) (m^3/sec)	
3.6	55.9b
4.5	65.6a
6.1	68.0a
SE±	2.855
Grain depth (B) (cm)	
5	53.0c
10	63.1b
20	73.5a
SE±	2.855

NS= Not significant Mean followed by same letter(s) on the same column are not different statistically at *P=0.05* using DMRT.

4.0 CONCLUSION

The design and construction of hybrid dryer for grain was achieved at the Department of Agricultural and Bio-resources Engineering workshop of the Ahmadu Bello University, Zaria, Nigeria. The dryer was evaluated and recorded highest drying efficiencies of 32.8% and 37.3% at 6.1 m^3/s air flow rate and 20cm grain depth respectively while the highest sensible heat utilization efficiencies of 68.0% and 73.5% was recorded at 6.1 m^3/s air flow rate and 20cm grain depth respectively. The evaluation showed that the system was effective in reducing energy loss and improving the overall drying process. Based on the outcome of this study, the followings are hereby recommended:

i. For the auxiliary heat source, a bigger kerosene stove or a propane gas should be incorporated for efficient heat generation.

ii. A photovoltaic cell should be used as source of power to fan/blower to allow on farm use of the dryer even where there is no electric power.

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