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Design of a Portable Grain Dryer

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Abstract

The goal of this paper is to design an electric grain dryer that will remove moisture from sorghum, beans and maize. Grain's high moisture content makes them difficult to store for an extended period. Natural sun drying or natural air drying is a time-consuming process that necessitates more time, space, and labor. The designed dry makes use of a forced draught mechanism, the heated air from the blower is passed through the grain-bed in the dryer. This electric grain dryer design is intended for local traders, small-scale farmers, and domestic users. The grain dryer's analysis and design will aid in the preservation of grains for food consumption at a variable temperature. Sorghum, wheat, and maize are among the grains considered in this analytical design. A drying chamber, heating element, fan, electric motor, frame, and three trays are among the design parameters. The frame was designed to be made of 2mm mild steel and have dimensions of (500 x 700 x 600) mm. The dryer has a 1 horsepower heating element, a 16-inch-diameter fan with a capacity of 60 cubic feet per minute and three trays. The dryer was designed to have a maximum capacity of 39kg per batch. Air temperature condition of 40°C at entry was used. The dryer was designed to reduce grain moisture content from 30 to 14 percent in fifteen minutes.

1 Introduction

Most of our locally produced foods are made from cereal grains like maize, rice, and millet. Grain drying is incredibly essential to prevent rotting and nuclei growth. Majority of these cereal grains are harvested during the rainy season, when there is not enough sunlight to cry them, thereby causing them to spoil. During harvest season, farmers can be seen dumping grain in small towns and cities across the country [1]. To ensure year-round availability and wholesomeness, the grains must be dried before storage. Moisture removal is generally done using natural or hot air [2] Food preservation has been going on since ancient times, when man recognized the extreme importance of keeping food as fresh as possible by removing as much moisture as possible. To dry food, early man relied on the sun's energy. It is preferable to use wood (coal) as an alternative to, or in addition to, solar drying for drying purposes [3]. Production rate has significantly increased due to improved manufacturing processes as a result of the development of new techniques, and the drying time-based bottleneck in the production line is no longer acceptable. Methods that rely on hot drying, require human handling, and have insufficient control over the drying process are no longer viable.

Modern drying techniques have, of course, been developed gradually. This method was inspired by advances in drying techniques, which were then applied to batches of products in intermittent dryers. Even today, such methods and equipment are adequate, if not susceptible to improvement. Thus, the goal of this research is to create a portable grain dryer for small-scale on-farm and domestic use.

2 Methodology

2.1 Components of the grain dryer

The dryer consists of six major components, namely: The drying chamber, trolley and trays, heater, fan/blower, control panel.

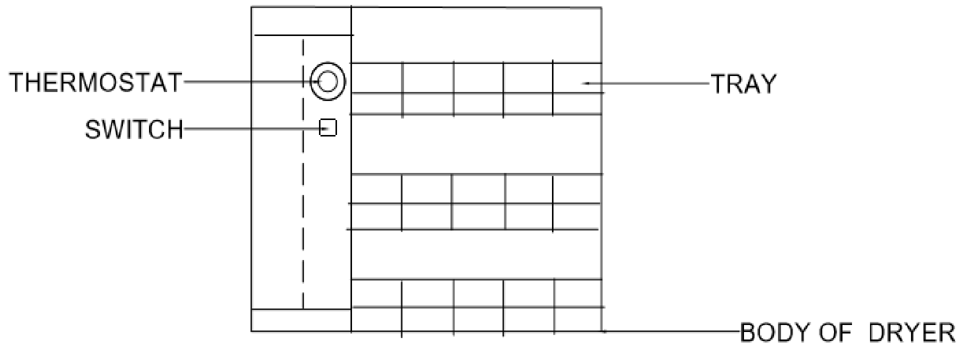

Figure 1. Diagram showing the arrangement of the trays in the drying chamber

2.1.1 The drying chamber

The drying chamber is 0.50 m long, 0.50 m wide, and 0.6 m tall. It is constructed of mild steel. Mild steel was chosen for this application due to its strength and heat transfer properties. The interior of the drying chamber is silver-painted to reduce heat loss through radiation, and each side of the chamber is insulated to reduce heat loss.

2.1.2 The trays

The trays are made of mild steel and have a length 0.46 m, width 0.46 m and depth of 0.1 m. The tray base could be solid or made of fine wire gauze which allows heated air to pass through grains.

2.1.3 The heater

The heater supplies heat for the drying of the grains and electrically powered. To ensure that the grains are properly dried within the specified drying temperature (40°C), the right power rating must be determined.

2.1.4 The fan/blower

The fan aids heat distribution by drawing ambient air from the surrounding environment into the heater housing and discharging heated air into the drying chamber. A suitable fan must be chosen to ensure proper heat distribution.

2.1.5 The control panel

The control panel is simply the unit that controls the system and maintains constant temperature in the drying chamber. It is made up of the: off and on switch, signal light, thermostat (thermocouple)

2.2 Design Considerations

The following factors were taken into account when designing the dryer:

- To avoid vapour accumulation, a vent was installed to allow easy flow of vapour picked up by the heated air from the grains to the atmosphere.

- The inner wall and fan of the dryer were made of stainless steel to ensure that the grains were not contaminated.
- To increase the rate of drying of the grains, an appropriate size of heater was chosen to raise the temperature of the drying air.

2.3 Design of the Dryer

The maize dryer's design was based on the following factors: the amount of moisture to be removed, the amount of air required to effect drying, the volume of air required to effect drying, the blower design and capacity, the amount of heat required, heat transfer, the actual heat used to effect drying, and the rate of mass transfer. The design was based on an ambient temperature (T_1) of 25°C, which is appropriate for steady flow systems [4]. Using the psychometric chart and normal temperature and 101.325 kPa barometric pressure, the initial humidity ratio (Hr_1) was determined to be 0.01 kg/kg dry air. The safe drying temperatures (T_2) required for drying maize is 40℃ [4].

2.4 Selection of Materials

The materials used in construction of the dryer were chosen so that it could be easily maintained, repaired, and obtained at a low cost. The metallic materials used in its construction allow the equipment to withstand heat, vibration, humid air, fatigue, and stress without failing during operation [5,6]. To prevent corrosion, all metallic parts were painted. Some of the materials used to construct the dryer's component parts include:

- Mild steel: It was used to construct the frame because it has great strength and can be easily welded.
- Galvanized sheet metal: This was chosen because of its toughness and ability to conduct and radiate heat. It was used to fabricate the heater and control panel cover.
- Saw dust: It is a poor conductor of heat and was chosen for lagging the body of the cabinet. Hence, heat loss from the cabinet can be greatly minimized.
- Wire mesh: It was used to make the drying trays. The mesh allowed heated air to pass through the materials to be dried.

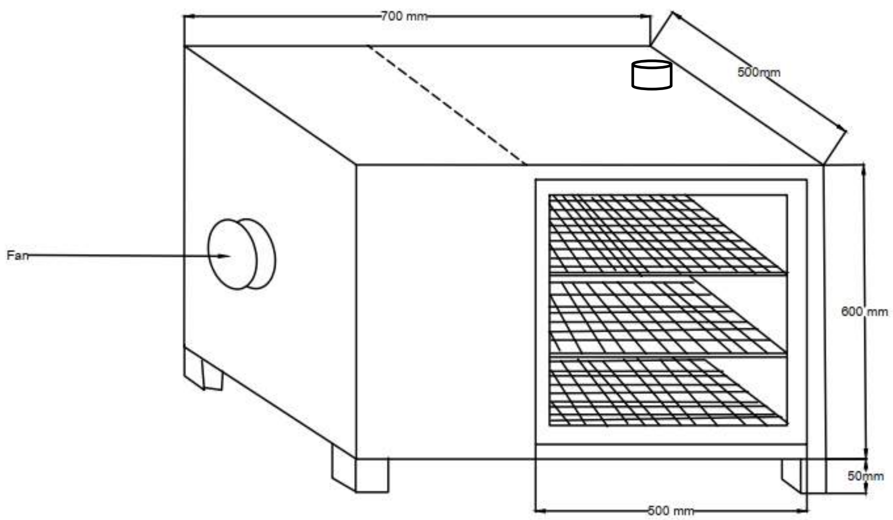

Figure 2. Diagram showing the grain dryer.

2.5 Design of the Drying Chambers (Dimension)

2.5.1 Selection of the heater

Length, width, and height of drying chamber are 0.5, 0.5 and 0.6 m respectively:
Volume of drying chamber = 0.5×0.5×0.6 = 0.15m3
Length, width, and height of trays are 0.46 m, 0.46 m, and 0.1 m respectively:
Volume of one tray = 0.46×0.46×0.1 = 0.02116 m3
Distance between subsequent trays = 0.1 m
Intended drying time = 15 min
Height at which grains will fill the trays = 0.08 m
Volume of grains per tray = 0.08×0.46×0.46 = 0.01693 m^3
Total volume of grains = Number of trays × volume per tray = 3×0.01693 = 0.05078 m^3
Using sorghum as an example, bulk density of sorghum = 770 kg m^{-3}
Total mass of rice = bulk density × volume = 770 kg m^{-3} × 1 × 0.05078 m^3 = 39.1 kg
Capacity of the dryer is therefore 39kg.

2.5.2 Amount of moisture removed

The amount of moisture removed from the fruit sample, (M_R) in kg is given by [3]:

$$M_R = M_W\left(\frac{Q_1 - Q_2}{100 - Q_2}\right) \quad 1$$

where;
M_W =mass of wet sample or the dryer capacity per batch, kg = 39kg
Q_1 = initial moisture content, %
Q_2= final moisture content based on experimental results, %

$$M_d = M_w - M_r \quad 2$$

M_d = mass of dried sample, kg
Q_1 = 30%
Q_2 = 14%
$M_R = 39(\frac{30-14}{100-14})$
M_R = 7.26kg
M_d = 39-7.26 = 31.74kg

2.5.3 Volume of air to effect drying

Volume of air to effect drying in m3 (V_a) was expressed using equations 3 and 4:

$$Q_a = \frac{M_R}{H_{r2} - H_{r1}} \quad 3$$

$$V_a = \frac{Q_a}{\rho_a} \quad 4$$

where;
Qa= quantity of heat to effect drying (kg)
Va = volume of air to effect drying (m^3)
H_{r1} and H_{r2} = are initial and final humidity ratios in kg/kg dry air respectively, H_{r1}=0.01 kg/kg dry air using the psychometric chart under normal temperature and 101.325 kPa barometric pressure where ambient temperature and relative humidity 32°C and 35 %, respectively.
H_{r2} = 0.027 kg/kg dry air after heat has been supplied when temperature rises to 40°C.
ρa = the density of air in kg m^{-3} is 1.115 kg m^{-3} at 40°C
M_R = as previously calculated from Equation 1 to be 7.26 kg.
Qa = $\left(\frac{7.26}{0.027-0.01}\right) = 427\ kg$

Va = $\left(\frac{427}{1.115}\right)$ = 383m^3

2.5.4 Quantity of heat required to remove moisture content

The quantity of heat (Qt) required to remove moisture content was expressed by [3]:

$$Q_t = MC_p\Delta T \quad 5$$

Where:
M =Mass of water
Cp = Specific heat capacity of air
$\Delta T =$ Temperature difference
Specific heat capacity of water = 4.182 kJ/kg^{o}C
Temperature difference between dried samples and initial temperature of dryer
Assuming the dryer is initially at 18^{o}C and experimental temperature is 40^{o}C.
$\Delta T =$ temperature difference = 40 – 18 = 22^{o}C
Qt = 7.26 x 4.182 x 22= 667.95J
Power = quantity of heat / time
Drying time interval = 15 minutes = (15 x 60) seconds = 900 seconds
Power = 667.95/900 = 0.74 kW
0.74kW = 1 hp

2.5.5 Calculation for the fan

The fan/blower serves the purpose of transferring heated air from the heat exchanger to the drying chamber. The fan aids in heat distribution by drawing ambient air from the surrounding to the heater housing and discharging heated air to the drying chamber. A proper fan must be selected so that proper distribution of heat is achieved.
Work done by heater = Work done on air

$$Q_{heater} = Q_{air} \quad 6$$

Work done by heater = 0.74 kW 7

Work done on air = $Q_{air} = MC_p\Delta T$ 8

Where:
M =Mass flow rate of air
Cp = Specific heat capacity of air = 1.005 kJ kgK^{-1}
$\Delta T =$ Temperature difference

$MC_p\Delta T =$ 740W
Mass flow rate = 740/(1.005*1000*22) = 0.0336kg/sec
Density of air at 40°C = 1.127 kgm^{-3}
Specific volume (v) = 1/1.127 = 0.8873 m^{3}kg^{-1}
Discharge = Mass flow rate × Specific volume = 0.0336×0.8873 = 0.0298 m^{3}sec^{-1}

Converting the value of the discharge obtained to cubic foot per min (cfm) for standard fan selection, we have:
1 cfm = 4.91747×10-4 m^{3}sec^{-1}
X cfm = 0.0298 m^{3}sec^{-1}
X = 60.57 cfm
Velocity of air through grain: Air flow rate/Cabinet area [cfm/ft^2]:

Length of drying chamber = 0.5 m = 1.6404ft
Area of floor = 1.6404 x 1.6404 = 2.69 ft^2
Velocity = 60.57/2.69 = 22.51 cfm/ft^2

2.5.6 Quantity of heat required to effect drying

$$H_r = (M \times H_k) + (H_L \times M_R) \quad 9$$

where M = dryer capacity per batch (kg) = 39 kg
$H_k = C_T(T_2-T_1)$, whereas C_T is specific heat of sorghum = 2.226 kJ/kg°C; and T_2-T_1 = 40 - 25°C,
H_L = latent heat of vaporization =2537 kJ/kg;
and M_R = amount of moisture was removed (kg)=7.26
H_r = (39x 2.226(40-25)) + (2537.43 x 7.26)
H_r is calculated to be 19,723.95.

2.5.7 Heat transfer rate

The heat transfer Q_{ht} could be computed as [6]:

$$Qht = hAT_b \quad 10$$

where;
h = heat transfer coefficient =is 14.7 $kW/m^{2o}K$ [2]
width of heater housing is 0.4m
length of heater housing is 0.2m
height of heater housing is 0.4m

A = surface area of heater housing= 0.4 x 0.4 = 0.16m^2;
T_B = temperature of hot air in the blower, 40 °C.
$Q_{ht} = hAT_b$
= 14.7 x 0.16 x (273 + 40) = 736.18kJ
The quantity of heat that could be lost through the blower in the process was calculated as

$$q_l = {KAT_{BE}}/{\delta_K} \quad 11$$

Q_l =The quantity of heat used lost in kJ
K = thermal conductivity of mild steel = 46 W/mK
A = surface area of the blower = 0.16m^2
T_{BE} = temperature difference between the hot air in the blower and the environment
= 40°C – 25°C = 15°C
δ = constant = 1
Q_l = (46 x 0.16 x 15)/1 = 110.4 Joules = 0.110kJ

2.5.8 The net heat transfer rate, Q_{htr}

T = drying time = 15 minutes = 0.25 hour

$$Q_{htr} = {(Q_{ht} - q_l)}/{t} \quad 12$$

Q_{htr} = (736.18-0.110)/0.25=2944.28 kJ

2.5.9 Actual heat used to effect drying (HD)

The quantity of heat used in effecting drying H_D in kJ can be determined by the given equation:

$$H_D = C_a T_C M_R \qquad 13$$

where C_a = specific heat capacity of air = 1.005 kJ/kg°C
M_R = amount of moisture to be removed = 7.26kg
T_c = temperature difference in the dryer cabinet = 40-25 = 15°C.
The quantity of heat is therefore calculated to be 109.44kJ.

2.5.10 Rate of mass transfer

The mass transfer rate Q_{mtr} in kg is determined by using Eq. (14):

$$Q_{mtr} = M_C A_t (H_{r2} - H_{r1}) q_2 \qquad 14$$

where Mc = mass transfer coefficient of a free water surface = 0.083kg/m^{2}s;
At = total surface area of the three trays = 0.46x0.46x3= 0.6348m^2.
(Hr2 – Hr1) = (0.028 - 0.01) = 0.018 kg/kg dry air;
and q2 = air flow rate = 1.788 m3/min. The mass transfer rate is therefore calculated to be 0.0017kg.

2.5.11 Thermal efficiency of the dryer

The thermal efficiency of the dryer is calculated using the formula [6]:

$$\eta_c = \frac{H_D}{Q_{ht} \times t}$$

$$\eta_c = \frac{109.44}{736.18 \times 0.25} = 60\%$$

where HD = the quantity of heat used in effecting drying = 109.44 kJ; Q_{ht} = heat transfer rate = 2944.28 kJ and t = drying time = 15 minutes = 0.25 hours

2.5.12 Insulation of the drying chamber:

Different materials are available for insulation but considering the drying temperature, availability, and cost of insulating material, saw dust has been chosen for installation Assuming a loss of 4 % of the quantity of heat produced, we can calculate the required thickness for saw dust:

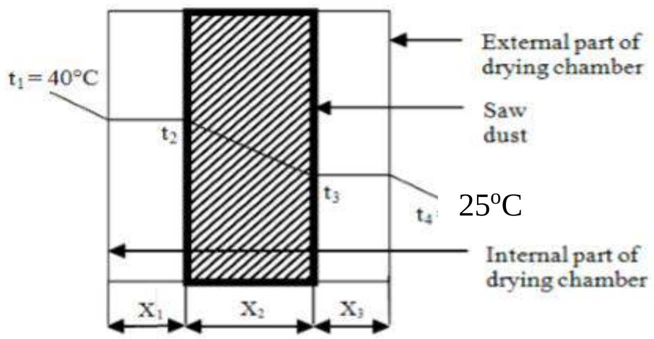

Figure 3. Insulation of drying chamber using saw dust

$X_1 = X_3$ = 2 cm
Quantity of heat per sec = 740W (from previous calculations):
4%of the quantity of heat produced sec^{-1} q= 29.6W
Quantity of heat lost unit area(q)

$$= \lambda_1 / X_1 \, (t_1 - t_2) \quad 15$$

$$= \lambda_2 / X_2 \, (t_2 - t_3) \quad 16$$

$$= \lambda_3 / X_3 \, (t_3 - t_4) \quad 17$$

$$= U(t_1 - t_2) \quad 18$$

Where: λ_1 and λ_3 = Heat transfer coefficient for mild steel = 46 W/m°C
λ_2 = Heat transfer coefficient of saw dust = 0.08 W/m°C
X_1, X_2 = The respective thicknesses of mild steel and sawdust
$X_1 = X_3$
Equation 1 and 2 we have:
29.6 = (46/0.02) x (40-t2)
Solving for t_2, in the above equation, we have:
t_2 = 40-0.0129 = 39.9871°C
$q = \lambda_3/X_3 (t_3-t_4)$
29.6= 46/0.02 (t_3-25)
t_3 = 25.0129 °C
$q = \lambda_2/X_2 (t_2-t_3)$
29.6= 0.08/X_2 (39.9871-25.0129)
X_2 = 0.0405m
Saw dust 4cm thick should be used as the insulating material to achieve a minimal heat loss of 4% from the drying chamber.

3 Results and Discussion

The proposed portable grain dryer has been designed to dry 39kg of sorghum, beans, and maize at 40°C from a moisture content of 30% to 14%. From the calculation, a heating element of 1 horsepower was required to reduce the moisture content in sorghum from 30% to 14% in fifteen minutes. The proposed dryer has sawdust as its insulating material to achieve minimal heat loss of 4%. The thickness of the sawdust was calculated to be 4cm. The efficiency of the dryer was calculated to be 60%. The efficiency can be said to be quite high as normal dryer efficiency for 30% moisture ration is 45% (10).

3.1 Cost analysis

Cost analysis: The cost is analyzed taking each component into consideration. The total cost of this dryer is divided into material, production, and miscellaneous costs.

3.1.1 Material cost for the frame and casting

The parameters used for the dimensions for the frame and casting of the machine are the length, L, width, W, and thickness, T. Total material cost is estimated at N 60,000.

3.1.2 Production cost

This is due to the cost of manufacturing the machine with the purchased materials. This includes complete machining and component part assembly. It includes the cost of labor, the cost of machining components, and the cost of welding electrodes. The total cost of production is estimated to be N15,000.

3.1.3 Miscellaneous cost

These are costs incurred during the project other than the material and production costs. These include transportation and research cost. Total miscellaneous cost is N5,000.

The total cost sums up to N80,000. This is relatively cheap as most foreign food dryers today go for N200,000 and above. The proposed design makes use relatively inexpensive materials in its construction, for example, sawdust has been chosen as the material of insulation instead of fiberglass to reduce cost.

4. Conclusion

A portable grain dryer design capable of drying fresh grains at 40^oC air temperature has been presented. The locally manufactured dryer is reasonably priced at eighty thousand naira (N 80,000 = $160 USD), which is 60% less the price of imported ones. The dryer can be used at home as well as on the farm for small-scale drying.

Nomenclature

M_R	Moisture removed
M_W	Dryer capacity per batch
Q_1	Initial moisture content
Q_2	Final moisture content
Q_A	Volume of air to effect drying
Va	Volume of air to effect drying
Q_t	Quantity of heat required to remove moisture content
ΔT	Temperature difference
H_r	Heat required to effect drying
Q_{ht}	Heat transfer rate
Q_{htr}	Net Heat transfer rate
C_T	Specific heat of sorghum
H_D	Actual heat to effect drying
Q_{mtr}	Mass transfer rate
η_c	Thermal efficiency of the dryer

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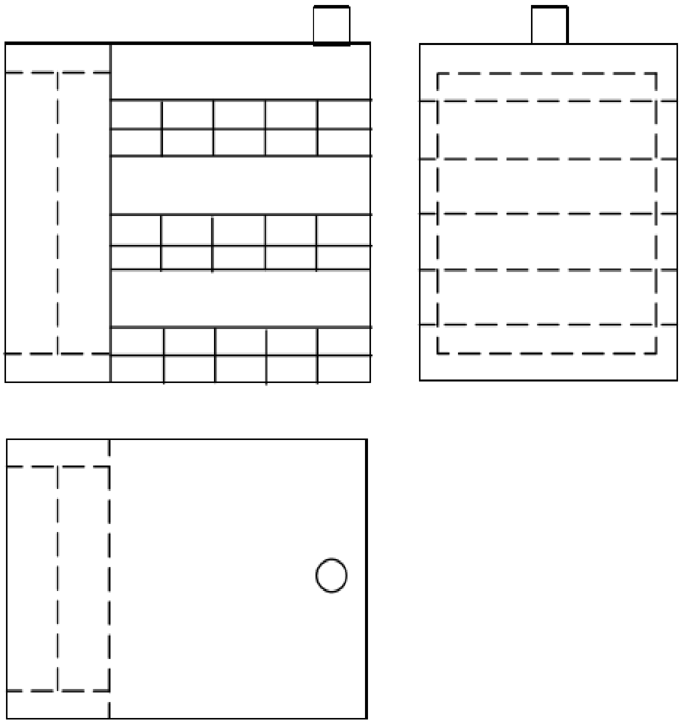
Appendix



First angle orthographic projection of the portable grain dryer