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Modification of A Locally Made Electric Crop Dryer

*T. B. Onifade, A. Taiwo and S.O. Jekayinfa
Department of Agricultural Engineering, Ladoke Akintola University of Technology, PMB, 4000, Ogbomoso, Nigeria.

Abstract

Physic nut is a biomaterial that litters villages during the seasonal period which requires effective drying for oil and bio-fuel production. However, the natural method of drying and the existing dryer are found ineffective due to prolonged drying time leading to poor quality control. Processing of dried physic nut is required to ensure preservation, availability throughout the year, easy shelling and extraction. The main objectives of this study were to improve on the design of an existing electric crop dryer with a view to optimize its efficiency, reduce the drying time and produce hygienic and quality dried physic nuts. The improvements on the design of the existing dryer were achieved by increasing the throughput on the capacity by improving the material selection for the various key component parts. An adequate size of electrical heating element with thermo-sensor which regulates the drying temperature and a centrifugal fan to blow hot air from the heat supply unit to the drying chamber were installed in the dryer. The results of the improvements carried out on the design of this dryer show that maintenance cost is reduced, since the fan is the only moving part which may rarely be faulty, drying time of physic nut was reduced, operation of the dryer does not require any specialization, the dryer is safer to operate, the energy required for loading and unloading have reduced since the trays provided are removable. Higher production rate and quality of dried physic nuts are achieved because drying temperature and air velocity can be regulated. The throughput capacity, efficiency and drying capacity of the modified crop dryer are 20 kg/batch, 79.84 % and 0.73 kg/h, respectively. This dryer is recommended for medium and large scale processors and dried products can be used for further application.

Keywords: physic nut, electric crop dryer, improvement on the existing design, temperature, drying time.

1. Introduction

Drying is a vital operation in the handling, transportation and storage of agricultural produce. The basic essence of drying is to reduce the moisture content of the product to a level that prevents deterioration within a certain period of time, normally regarded as the "safe storage period" (Saeed et al., 2008). Practically, drying is a simultaneous heat and mass transfer processing its ordinary application; this involves vapourisation of water in the liquid state, mixing the vapour with the drying air and removing the vapour naturally or mechanically from agricultural materials (Sharma et al., 2009). Sufficient heat for vapourisation of product moisture must be supplied by reducing the sensible heat of the drying air or by applying heat directly to the product by conduction, radiation, dielectric heating, freeze-drying etc. Utilization of sensible heat energy of the hot air is by far the most common means of drying materials (Ezekwe, 1995; Onifade, 2015). The drying time becomes shorter with higher temperatures, which was expected due to an increase in the drying rate, because there is increase heat transfer potential between the air and kiwifruit slices, thus, enhancing the evaporation of moisture water from kiwifruit slices (Mohammadin et al, 2008). Similar behavior was reported by several authors; Akendo et al. (2008) observed the behavior in dewatering and drying process of water hyacinth petiole. Belghit et al. (2000) investigated the drying kinetics of aromatic plants. Falade and Abbo (2007) and Madamba et al. (1996) also worked on air drying characteristic of date palm fruits and garlic slices respectively.

Whatever type of drying method used, agricultural materials go through three phases, which vary in time according to the characteristics of both air and product. The product temperature and air humidity content, have a very distinct evolution in the course of these different phases (Ajibola 1989; Akanbi et al., 2006). The first phase (in which the drying rate increases) is short and corresponds to the rise in temperature of the product until it reaches an equilibrium when the product receives as much heat from the air as it needs to give to the water to vaporize. The drying rate increases, because the exchange of moisture between the product and the air is efficient as the product is heated. The second phase, with a constant drying rate, corresponds to the evaporation of the free water on the surface of the product, which is permanently renewed by the moisture coming from inside the product. During this phase, the drying velocity is constant as long as the characteristics of the air and its velocity going over the product are constant. The third phase (decrease in drying rate) corresponds to the evaporation of bound water. The free water, which migrated from the inside to the outside of the product to be transformed into water vapour, has completely disappeared by the end of second phase. Moreover, the loosely bound water, which is the easiest to extract, evaporates first (Ajibola 1989; Akanbi et al., 2006). During this last drying phase, the water, which is extracted, is more and more tightly bound to the product, and therefore more and more difficult to extract. The drying rate decreases as one approach the end of the operation.

Dryers are one of the most important equipment in the food processing industries. Many dryers have been developed and used to dry agricultural materials in order to improve their handling, transportation and storage conditions (Mulhlbauer et al., 1996). It was discovered that out of over 200 different types of dryers are manufactured for different applications in industry, but only 20 basic types and their variants are commonly used in practice (Ehiem et al., 2009). Artificial dryers employ the application of heat from combustion of fossils fuels and biomass resources, directly or indirectly, and in both natural and forced convection systems. Mechanical dryers long used in developed countries required special skill to operate them as farming and grain handling systems developed (Ehiem et al., 2009). Most of the dryers used are powered by energy such as electricity (Berinyuy, 2000), solar energy and other forms of energy. The continuous tunnel dryers, vacuum dryers or solar dryers are most common dryers use drying for vegetables.

The cabinet dryer has a chamber to hold the product to dry and a means of moving air to generate heat for the drying process. The cabinet dryer consist of three main unit; the drying unit, the heat supply unit and the fan compartment. The drying unit is made up of drying chamber and the drying trays where the product to be dried are placed for drying (Adzimah and Seckley, 2009; Ehiem et al., 2009). The heat supplied from the burner is transferred to the drying chamber by the principle of conductive and convective heat transfer. The drying trays are made of mild steel; the tray base could be built of wire mesh to allow heated air to pass through the product (Adzimah and Seckley, 2009). The heat supply unit comprises of the heat exchanger and the furnace, the furnace is located underneath the heat exchanger, it is where heat is being exchanged between the furnace and the cool air. The heat supply for the drying of the product is electrically powered. The fan or blower creates forced air flow within the dryer. The air conveys the heated air needed to remove moisture from the product being dried while simultaneously providing a means of transferring the moisture removed from the product outside the drying unit. Some dryers have control panel that controls the system and maintains constant temperature in the drying chamber. This is made up of the off and on switch, signal light (indicator) and thermo-sensor (Adzimah and Seckley, 2009).

It has been observed in our localities that the traditional method of drying physic nut and materials by peasant and resource poor is stressful because it involves a lot of drudgery during the peak of harvest. This method is time consuming and ultimately resulting in poor quality products due to contamination while the materials are spread on floors and ground. Thus, low income output is produced by the farmers. The fact that the cost of imported dryers are often beyond the reach of the peasant farmers who constitute the critical mass of the farmers group has made the modification of the dryer in this study inevitable. The products dried with the existing crop dryer are often under dried or over dried and sometimes get roasted thus resulting in diminished quality and oil content. The dryer also has a lot of deficiency in terms of drying time, efficiency and productivity. There is need to modify the dryer with a view to improve its efficiency and reliability.

The main objective of this study was to improve performance of an existing batch dryer for drying agricultural materials; hence physic nut was used as test material. The specific objectives were to construct a larger frame, drying chamber, an open ended air inlet and outlet pipes and equip the dryer with removable wire mesh trays, incorporate temperature and blower regulators and evaluate its overall performance in term of efficiency, drying time and quality of products.

2. Materials and Methods

The existing crop dryer was used in a farm settlement near Ogbomoso town (8^{o}07' N, 4^{o}16'E) in Nigeria. The problems associated with its operation due to the shortcomings in its design were identified as the machine was properly examined. The necessary procedures were carried out to eliminate the causes of the shortcomings observed vividly.

Components of the existing crop dryer

The existing crop dryer and its drying (cabinet) chamber are shown in Figure 1 and 2, respectively. The dryer is made up of the following component parts:

- The dryer frame
- The drying chamber
- The blower unit
- The heating chamber

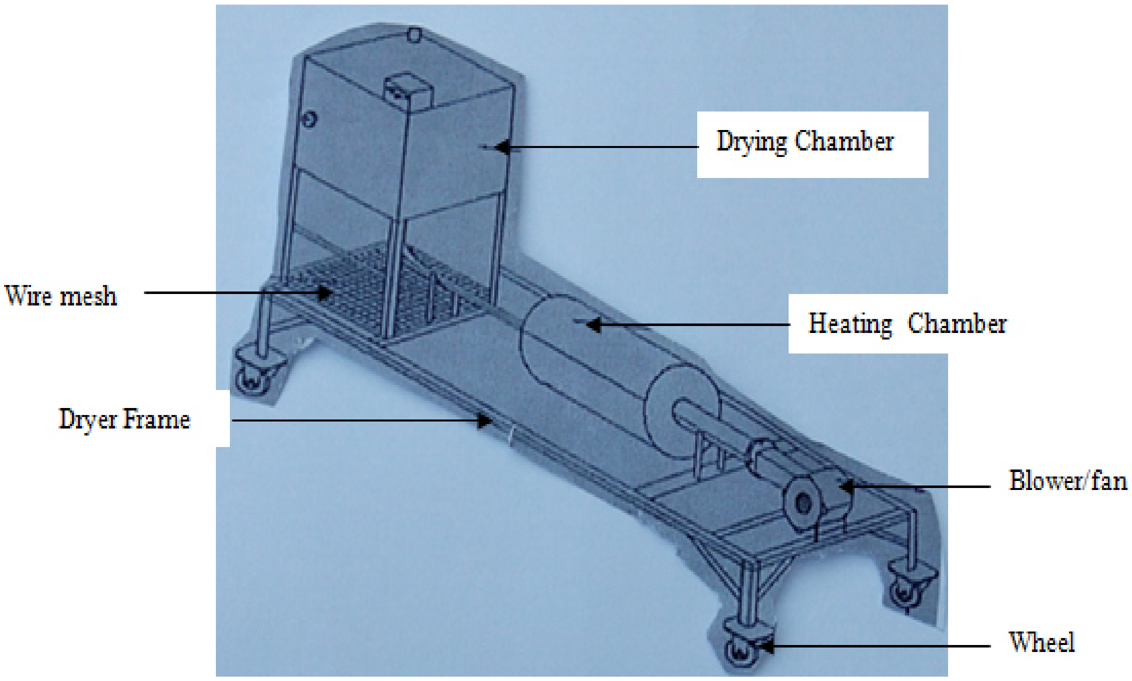

Figure 1: Pictorial view of the existing crop dryer

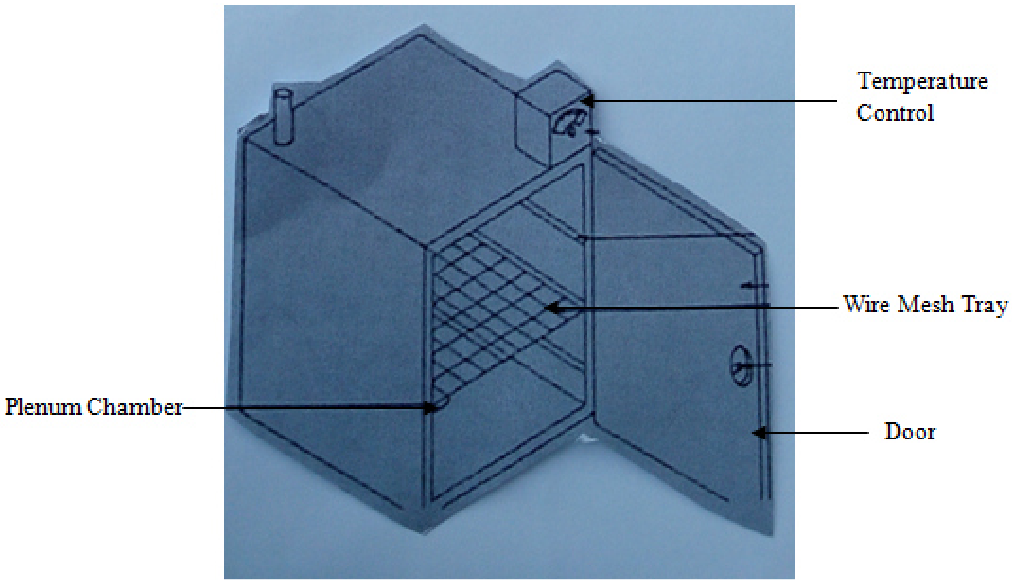

Figure 2: Pictorial view of the existing drying cabinet

Problems identified with the existing design of the crop dryer:

- Longer drying time of the materials
- Smoke from the drying shed during operation
- Poor heat distribution (caused under drying)
- Over-drying of materials at the bottom of drying chamber (reducing quality and quantity)
- Loading and unloading of material is stressful (trays are not removable and very hot)

The proposed modification on the existing crop dryer

The improvement on the existing crop dryer was carried out on the basis of the problems identified during its initial performance evaluation. Larger drying chamber in which temperature and air velocity regulators were incorporated was constructed. Other reconstructed functional elements of the piece of equipment are two open ended air inlet and outlet pipes, new electric heating element and wire mesh drying trays. The orthographic projection of the improved crop dryer in first angle projection is as shown in Figure 3.

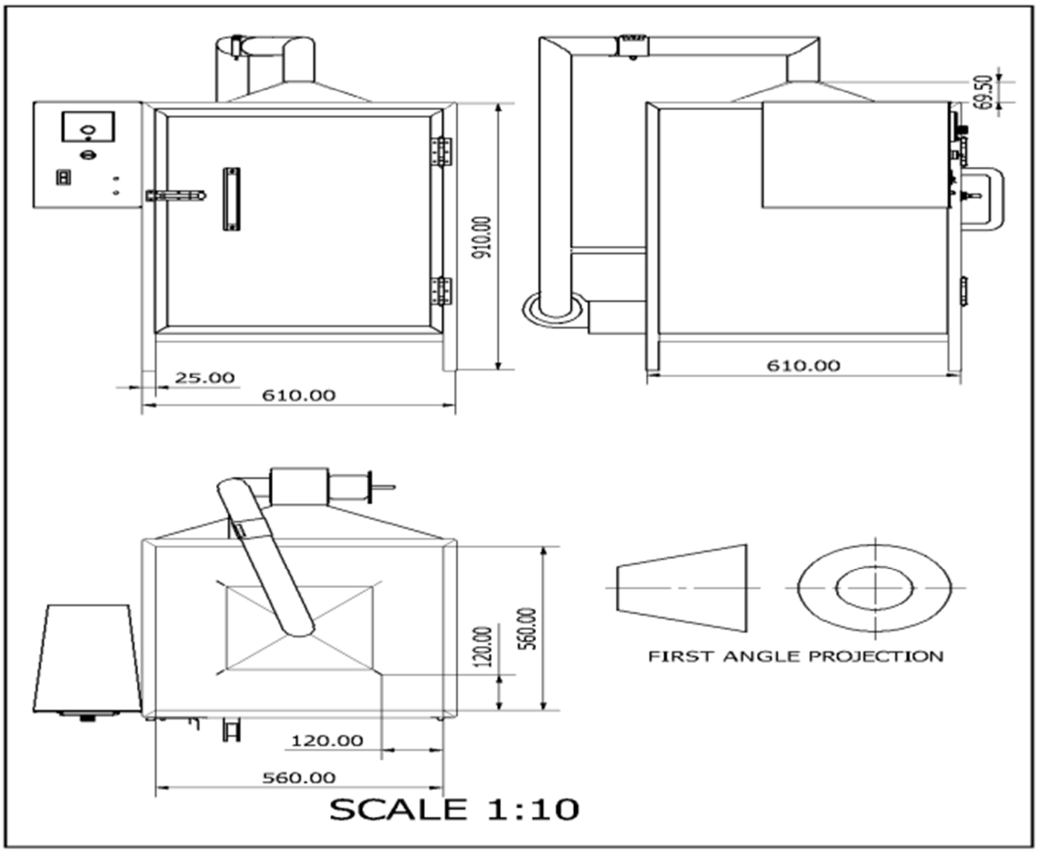

Figure 3: Orthographic projection of the improved crop dryer

2.1 Design Considerations for the Improved Crop Dryer

Some factors were considered in the design modification of the crop dryer in order to produce high quality and large quantity of products to be dried. The factors considered are as follows;

- The availability and cost of materials required (relatively cheaper than imported ones),
- Ease of operation
- The drying equipment is a batch type
- Can be operated by one person
- Size and weight of the machine
- Ease of Maintenance
- Temperature and air velocity can be regulated, capability to use the dryer to dry different crop materials.
- Safety

2.2 Selection of Materials

The materials used for the construction of the dryer were such that could make it to be easily maintained, repaired, and obtained at relatively lower costs. The metallic materials used to build the equipment enable it to withstand heat, vibration, humid air, fatigue and stress without failure during operation (Ehiem, 2008; Onifade, 2015). All the metallic parts were painted to prevent corrosion. Some of the materials used to build the component parts of the dryer 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 heat exchanger and control panel cover.

- **Fibre glass:** 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.

Component parts of the improved crop dryer

The new dryer consists of the following parts as shown in Figures 4 and 5;

- Enlarged machine frame
- Control panel (incorporated with temperature and fan regulator)
- Steam pipes (for inlet and outlet air)
- Wire mesh trays (removable)
- New industrial electric heating element

2.3 Description, Construction and Analysis of the Dryer

The modified crop dryer consists of three sections viz; the drying, heating and blower sections as follows;

The drying section

The drying chamber was built with mild steel. The drying chamber measured 0.97m x 0.915m x 1.25m in length, width and height respectively giving a volume of 1.109 m^3. The interior walls of the cabinet were lined with fibre glass, 20 mm thick in order to prevent humid air removed from the drying product and to reduce heat loss.

Figure 4: Pictorial views of the crop dryer

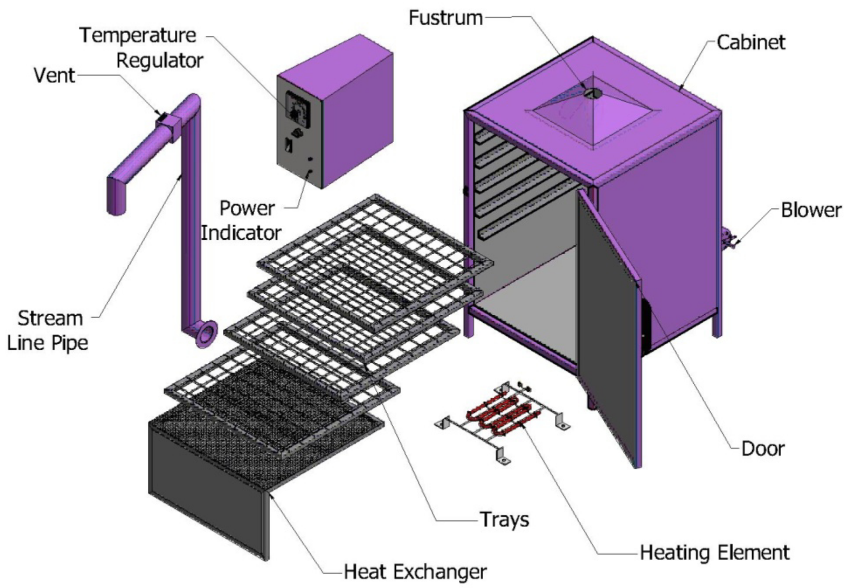

Figure 5: Exploded view of the crop dryer

The door was located at the front side order to make loading and unloading of the trays very easy. The length and width of the door were measured to be 0.95 and 0.895 m with surface area of 0.850 m^2. The diffuser (like frustum in shape) was attached to the cabinet and bolted to the blower air outlet as shown in Figure 4.The bottom and the top dimensions were 0.12 m x 0.10 m and 0.25 m x 0.13 m in length and width, respectively. The diffuser helped to spread the hot air from the exchanger to the drying products, so that all the products had contact with the hot air at the same time. The top of the cabinet was shaped like a frustum, so as to hasten the removal of humid air which might result to condensation from the dryer.

The cabinet stand was built from mild steel with 0.97 m x 0.915 m in length and width respectively and 0.32 m above the ground. This helps to raise the cabinet above the ground to avoid possible decay and insects' infestation. The wire mesh tray frames and bodies were made of mild steel in order to make them strong enough for supporting the weight of the samples and ensure proper aeration of the drying products. Each tray was 0.85 m long, 0.80 m wide and 0.015 m high with a volume of 0.0102 m^3 and thus making the total volume of 0.0408 m^3 for the four trays. The uniform gap of 0.09 m allowed between trays was to prevent condensation and improve vaporization process on the drying product.

The heating section

The source of heat in this section is electrical power. The required drying temperature can be set on the control panel (ranging from 0 to 300 °C), which makes the dryer a multipurpose one. An electrical heating element of 1 kWh capacity was placed at the base of the cabinet and joined together with four element holders. The heat exchanger measured 0.85 m x 0.80 m x 0.79 m in length, width and height, respectively and accumulated heated air. A perforated sheet metal of 0.85 m x 0.8m was placed at 0.1 m above the heat exchanger to facilitate uniform distribution of hot air to the drying chamber. At the lower end of the heat exchanger was an air inlet of 0.18m x 0.01m in length and width respectively, through which ambient air entered it. On top of the drying cabinet was mounted a steam pipe through which hot air exhausted from the chamber. The steam pipe was built with mild steel of 0.002 m thickness, 0.46 m length and 0.05 m diameter. It had a total surface area of 1.807 m^2. There was a vent across the steam pipe measured 0.01 m x 0.01 m x 0.01 m in length, width and height respectively with an area of 0.001 m^2. This encourages quick passage of hot air from the drying chamber to the atmosphere. The side has small flange which covers the pipe opening.

The blower section

A centrifugal fan was installed in the dryer with rating of 500 W. The air velocity can be controlled on the control panel with a regulator ranging from 1.0 to 5.0 m/s. The blower case was constructed with mild steel with

0.52 m diameter and was bolted to the base (back) of the crop dryer with a cylindrical duct of 0.2 m diameter and 0.3 m long. The total surface area of the blower casing and the cylindrical duct was 0.89 m^2. The blower case housed a centrifugal fan which blew ambient air to the heater.. The blower capacity was 320 kg/min. The blower case was bolted to the diffuser. Its shaft was attached by an elbow joint where the electric motor shaft was fitted. The universal joint ensures that the electric motor and the blower align as shown in Figures 4.

2.4 Design Analysis

(a) Amount of moisture removed

The amount of moisture removed from the fruit sample, (M_R) in kg was evaluated using equation 1 as stated by Adzimah and Seckley (2009):

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

where;
M_w= mass of wet sample or the dryer capacity per batch, kg
Q_1 = initial moisture content, %
Q_2 = final moisture content based on experimental results, %
M_d = M_w- M_R = mass of dried sample, kg

$$M_d = M_w - M_R \quad (2)$$

Q_1 = 84.3 % ;
Q_2 = 16.63 %

$$M_R = 20\left(\frac{84.3-16.63}{100-16.63}\right)$$

$$M_R = 16.23\ kg$$

$$M_d = 20 - 1.23\ kg$$
$$= 3.77\ kg$$

(b) Volume of air to effect drying

Volume of air to effect drying in m^3 (V_a) was expressed as shown in equation 3 and 4 (Ajisegiri et al., 2006):

$$Q_a = \frac{M_R}{Hr_1 - Hr_2} \quad (3)$$

$$V_a = \frac{Q_a}{\gamma_a} \quad (4)$$

where;
Q_a= quantity of heat to effect drying (kg)
V_a= volume of air to effect drying (m^3)
Hr_1 and Hr_2= are initial and final humidity ratios in kg/kg dry air respectively,Hr_1 =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 ^{o}C and 35 %, respectively.
Hr_2 = 0.027 kg/kg dry air after heat has been supplied when temperature rises to 40 ^{o}C.
γ_a= the density of air in kg m^{-3} is 1.115 kg m^{-3} at 0 ^{o}C based on the properties of common fluids (Ehiem et al., 2009).
M_R = as previously calculated from equation 1 to be 16.23 kg.

$$Q_a = 954.71\ kg$$

$$V_a = \left(\frac{1475.23}{1.115}\right) m^3$$
$$= 856.23\ m^3$$

(c) Quantity of heat required to remove moisture content

The quantity of heat (Q_t) required to remove moisture content was expressed in equation 5 as stated by Adzimah and Seckley (2009).

$$Q_t = M_R C_p\, \Delta T \quad (5)$$

where;
$M_R = mass\ of\ water\ removed$
$= 16.23\ kg$;
$C_p = specific\ heat\ capacity\ of\ water$ (4.182 kJ/ kg^{o}C)
ΔT = Temperature difference between dried samples and initial temperature of dryer
Assuming the dryer is initially at 15 ^{o}C and experimental temperature is 40^{o}C.
$\Delta T = temperature\ difference = (40 - 15) = 25$ ℃

$Q_t = 16.23 \times 4.182 \times 25$
$= 1696.85$ J $=1.697 \times 10^3\ kJ$
$Power = quantity\ of\ heat/time$
$drying\ time\ interval = 1\ hour\ (3600 secs.)$
$power = 1.697 \times 10^3/3600$
$= 0.4713\ kW$
Since, $0.746\ kW = 1hp$
From the above calculation a heating element of $1hp$ was required in case the atmosphere is highly humid.

(d) Blower capacity

The blower serves the purpose of transferring heated air from the heat exchanger to the drying chamber. The selection was based on the characteristics of centrifugal fan performance curve equation 6, (Ehiem et al., 2009).
According to Ehiem et al. (2009), the Blower Capacity (BC) was calculated from equation 6;
$$BC = Q_a + Q_n(n) \quad (6)$$

From equation 3.3
$Q_a = quantity\ of\ heat\ to\ effect\ drying = 854.71\ kg$
$r_a = density\ of\ air = 1.115\ kg/m^3$
$q_2 = volumetric\ flow\ rate\ \ m^3/min$
where;
$$Q_n = r_a \times q_2 \quad (7)$$
Q_n = air flow rate, kg/min
$Q_n = 1.115 \times 198.1$
$= 220.8\ kg/min$
n = percentage safety factor that ensures an adequate supply of air in all operating conditions at 15 % but usually 10-20 % (Ehiem et al., 2009). BC was therefore calculated in kg/min by substituting appropriate values into equation 7.
$BC = 854.71 + 220.80(0.15)$
$= (3854.71 + 33.12)\ kg/min$
$= 887.83/60\ sec$
$BC = 14.797\ kg/s$

(e) Heat transfer rate

According to Ehiem et al. (2009), the heat transfer (Q_{ht}) could be computed as:
$$Q_{ht} = hAT_B \quad (8)$$
where;
h = heat transfer coefficient = N_uK/d and with Nu (Nusselt number) = $0.13R_a^{0.33}$ with $R_a = 109$;
K = thermal conductivity = 0.0305 kW/mK
d = diameter of the heat exchanger = 0.56 m, the value of h, is 6.607 kW/m^{2o}C;
A = surface area of the heat exchanger = 0.7389 m^2;
T_B = temperature of hot air in the blower, 80 ºC.
$Q_{ht} = hAT_B$
$= 6.607 \times 0.7389 \times 80$
$Q_{ht} = 390.55$ kJ

The quantity of heat that could be lost through the blower in the process was calculated as:
$$q_L = KAT_{BE}/\delta_k \quad (9)$$
where;
$q_L = quantity\ of\ heat\ lost\ (kJ)$
$K = thermal\ conductivity\ of\ mild\ steel = 58\ W/mK$
$A = surface\ area\ of\ the\ blower = 0.89\ m^2$
$T_{BE} = temperature\ difference\ between\ the\ hot\ air\ in\ the\ blower\ and\ the\ environment$
$= 80 - 32$ ℃ $= 48$ ℃;
$\delta_k = constant = 1$
$q_L = 2.477\ kJ$
$Q_{htr} = the\ net\ heat\ transfer\ rate$
$t = drying\ time$= 24 h

$$Q_{htr} = (Q_{ht} - q_L)/t \quad (10)$$
$$= 388.073/24$$
$$=16.169 \text{ kJ/h}$$

(f) Actual heat used to effect drying (H_D)

The quantity of heat used to effect drying in kJ, H_D, was determined as given in equation11:

$$H_D = C_a T_c M_R V_c \quad (11)$$

where;

C_a = specific heat capacity of air = 1.005 kJ/kg°C;

M_R = amount of moisture removed from the sample in kg;

experimental temperature, 80°C and environmental temperature, 32 °C

T_c = temperature difference in the dryer = (80- 32) °C = 48°C.

V_c= volume of drying chamber =11.09 m^3

$$H_D = 16.32 \times 48 \times 1.005 \times 11.09$$
$$= 8730.94 \text{ kJ}$$

(g) Rate of mass transfer

The mass transfer rate Q_{mtr} in kgm^3/s^2 was determined by using equation 12:

$$Q_{mtr} = M_c A_t (H_{r1} - H_{r2}) q_2 \quad (12)$$

where;

M_c= mass transfer coefficient of a free water surface, 0.083kg/m^{2}s;

A_t= total surface area of the four trays inside the dryer, 2.72 m$^{2;}$

$H_{r1} - H_{r2}$ = the difference in initial and final humidity ratios (0.028-0.01) = 0.018 kg/kg dry air;

q_2 = air flow rate, 198.1 m^3/min = 3.302 m^3/s

Q_{mtr} = 0.013 kgm^3/s^2

2.5 Performance Evaluation

Physic nuts used as test material were collected from bushes in rural areas near Ogbomoso town, (8°07' N, 4°16'E) in Nigeria. The experiments were performed in the Laboratory of the Department of Agricultural Engineering, LAUTECH, Ogbomoso. The dryer was adjusted to a preset temperature for about half an hour prior to achieve the steady state. The experiments were carried out inside the cabinet of crop dryer and dried at selected temperatures of 40, 50, 60, 70 and 80 °C and air flow velocity of 1, 2, 3, 4 and 5 m/s. The samples were weighed initially and put in four wire mesh baskets with 5 kg each, and placed on the drying trays and dried as thin layer inside the modified electric crop dryer (Figure 4) and the measurement was taken hourly with three replications. The ambient air was heated up by the electric heater and uniformly spread by the heat exchanger through the diffuser to the samples inside the drying chamber.

(a) Thermal efficiency of the dryer

The thermal efficiency of the dryer η_c was calculated from equation 13 as stated by Ehiem (2008):

$$\eta_c = \frac{H_D}{t \times Q_{ht}} \times 100 \quad (13)$$

where;

H_D = *the quantity of heat used in effecting drying*, kJ;

Q_{ht} = *heat transfer*, kJ

t = *drying time*, 24 *h*

$$\eta_c = \frac{8730.94}{24 \times 390.55} \times 100$$
$$\eta_c = 93.14\ \%$$

(b) Drying rate of the palm kernel

The drying rate was determined and measured in kg/mol/hr using equation 14 as stated by Ehiem (2008) and Ceankoplis (1993).

$$R_c = \frac{M_d}{A_s} \times \frac{Q_1 - Q_2}{t} \quad (14)$$

where;

R_c = *drying rate* $\left(\frac{kg}{mol}\right)$;

$Q_1 = initial\ moisture\ content\ (84.3\ \%\ wb)$;
Q_2 = initial moisture content (16.63 % db)
M_d = weight of the dried product (see eq. 1)
= 3.77 kg
A_s = surface area of the dried sample
= 0.076 m^2;
t = optimum drying time, 27.5 hours
R_c = 0.959 kg/mol/hr

3. Results and Discussions

The capacity of the dryer is 20 kg/batch; this indicates that the modified dryer is capable of drying 20 kg of physic nuts at a time greater than 9 kg of the existing dryer. The drying capacity is 0.73 kg/h, the drying rate of physic nut 0.93 kg/ mol. of H_2O/h while the efficiency of the modified dryer, 93.14 % was higher than of the existing dryer, 54.36 %. The capacity of the dryer and the efficiency of the drying device are very important to increase productivity. These parameters in this study are different as compared to other developed dryers reported by Ehiem 2009 and Folaranmi (2008) for drying tomato (256.8 kg, 84 %) and grains (50 kg, 21 %), repectively; this can be attributed to varying factors such as the differences in the inherent energy requirement during the drying process and materials used for the construction of the equipment. In the findings of Varum (2010), the solar crop dryer integrated with solar air heater had overall efficiency of 10 %, which was quite a fair performance in terms of solar energy utilization. It was also stated by Mohanraj and Chandrasekar (2009) that performance of a forced convection solar dryer integrated with gravel as heat storage material for chilli drying had efficiency of 21 %. Ehiem, et al. (2009) worked on a developed industrial fruit and vegetable dryer using plywood and burnt bricks as part of the component materials, the researchers found out that the dryer capacity and thermal efficiency of the dryer were 256.8 kg and 84 % respectively. However, the results varied with the type of dryers. This is an indication that drying process in the other developed dryers is more energy intensive and possibly high heat loss is generated.

The blower capacity is 322 kg/min while the values of 16.23 kg and 856.23 m^3 were the amount of moisture removed from the sample and the volume of air to effect drying respectively. The quantity of heat required from the heating element was 1696.85 kJ while the actual heat used to effect drying of the produce was 8730.94 kJ. The mass and heat transfer rate gave 0.0805 kgm^3/min and 387.5 kJ/s respectively. The mass of the material decreased as temperature and air velocity increased due to increase heat transfer potential between the air and the palm kernels which enhanced evaporation of moisture from the materials (Dincer, 2002 and Doymaz, 2006). But reverse is the case in the findings of Hadi et al., (2014), the value of heat transfer rate due to evaporation in the heat pump tumbler dryer was investigated to be very low. This may be due to smaller drying space (medium) which may affect the escape of moisture. This indicated that the drying mechanism achieved the intended function; it evaporated excess moisture from the physic nuts because the physical nature of the specimen produced showed that the drying temperature and air velocity had positive effects on the test materials. Though, the effect of temperature on the condition of drying is well documented in the literature (Akpinar et al., 2003 and Mohammadin et al., 2008). The samples were not cake dried (burnt) like previous materials obtained from the existing dryer. This indicates the quality of the materials produced by the modified crop dryer.

The drying period was longer, 28 h for materials dried at temperature 40 ℃ while at 50, 60 and 70 ℃, the samples dried for 26, 24 and 20 h respectively. The shortest drying time, 18 h was at 80 ℃. The rate of evaporation in the product was faster when the temperature was higher and this resulted to decrease in drying time (Dincer, 2002 and Akpinar et al., 2003). But from calculation, it was observed that thermal efficiency was higher and reliable at 60 ℃. The time to reach equilibrium moisture content (16.5 %, dry basis) from the initial moisture content (84.3 %, wet basis) at the various drying air temperature was found to be between 18 and 28 h. This result indicates that the rate of moisture loss decreased due to variation in temperature and air velocity to obtain different drying time.

4. Conclusions

The crop dryer has been modified using low price available materials and evaluated. The temperature and air velocity can be controlled since regulators are incorporated on the dryer. With this modification, the problems of safety, drying time, quality and quantity of dried products associated with traditional drying method and existing dryer has been eliminated. The modified crop dryer is environmental and user friendly and requires no special skill to operate. The capacity of the dryer is 20 kg/batch; this indicates that the modified dryer is capable of drying 20 kg of physic nuts at a time greater than 9 kg of the existing dryer. The drying capacity is 0.73 kg/h and the thermal efficiency of the modified dryer for drying palm kernel has been determined to be 93.14 % at 60 ℃.

The capacity of the dryer and the efficiency of the drying device increased productivity. In addition, the equipment is required to be properly maintained and kept clean to provide a more reliable and longer service life. This design is recommended for small and medium scale production.

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