Research Journal of Applied Sciences, Engineering and Technology 1(2): 44-53, 2009
ISSN: 2040-7467

Submit Date: June 08, 2009 Accepted Date: July 15, 2009 Published Date: August 31, 2009

Design and Development of An Industrial Fruit and Vegetable Dryer

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Abstract: An industrial fruit and vegetable dryer was designed and developed to reduce vegetable wastage and improve their storage conditions. It consists of three units: drying chamber, blower and heat exchanger. The performance test and evaluation was conducted using split plot in Randomized Complete Block Design (RCBD) with a total number of 756 observations (3 sizes x 3 air flow rates x 14 hours drying time x 6 replications) using tomato as the test material at an average drying chamber temperature of 50 ºC for safe drying of tomatoes. The size (small, medium and large), air flow rate (18.3 m/s,18.8 m/s and 19.5 m/s) and drying time (0-14 hours) has highly significant ($P \leq 0.01$) effect on gram weight of the tomato slices being dried. For all the tomato sizes and at all air flow rate levels, gram weight of the tomato decreased with increase in drying time. Also for all the sizes at all drying time levels, gram weight decreased with increase in air flow rate. The dryer which has a mean drying capacity of 258.64 kg of tomatoes per batch with a thermal efficiency of 84 % and drying rate of 40 g/hr, at relative humidity of 35% improved the drying time of vegetables and is recommended to industrial users.

Key words: Design, development, dryer, fruit, industrial, vegetable

INTRODUCTION

Fruits and vegetables are agricultural products that are known for their rich vitamins, high concentration of moisture and low fats. They are highly perishable due to excess moisture present in them especially at harvest. Fruits and vegetables are seasonal crops and are mostly available during the production season. Wills *et al.* (1998) stated that there was a high increase in production of vegetable and fruits from 112 million tones in 1970 to 203 million tones in 1994. The demand for vegetables by the growing population has not been met despite the increase. This is as a result of wastes that result from biological and biochemical activities taking place in the fresh product and unfavourable storage conditions, inefficient handling, transportation, inadequate post harvest infrastructure and poor market outlets. Rahman *et al.* (1992) estimated that as much as 25 % of some vegetables are wasted during peak production period. In Nigeria alone, up to 50 % of harvested tomatoes get spoilt annually (Musa-Makama *et al.*, 2005) causing seasonal shortage and fluctuations in supply and prices. Fruits and vegetable can be successfully preserved by reducing their moisture content to a level that will discourage the activities of micro-organisms and fungi from deteriorating them. Microbial activities are not active when the moisture content of a product is below 10 %. Saravan (1999) reported that moisture content above 4.13 %(db) or 4% (wb) for vegetables will result to deterioration. Hence, harvested vegetables must be stored dry (5% moisture content wet basis) (FAO, 1981) to prevent attack and deterioration by activities of micro organisms and fungi.

Drying of produce especially vegetables is one of the oldest forms of food preservation methods known to man. It is the removal of moisture from the product to an optimum level in order to prevent deterioration and preserve their nutritive values. Drying is a simultaneous heat and mass transfer process. The heat stirs up the moisture in the product by external medium usually air while the moisture in form of vapours through the product tissue capillaries. Relative humidity is a very important factor in drying in that it determines the moisture holding capacity of the drying air. According to Sharaf-Eldeen *et al.* (1979) relative humidity up to 30% has negligible effect on the drying rate of grains and other agricultural products. Apart from exposing the product to direct sun energy (traditional method of drying), there are indirect methods of achieving better quality dried products that are free from inefficiencies of sun drying that is characterized by the problems of losses, contaminations, rewetting and uncontrolled drying rate. This results to loss of flavour, colour, taste, and case hardening, heat stress and contamination by birds, flies and animal droppings. Eke (1999) reported that farmers in Zaria, Nigeria have troubles with sun drying of vegetables, most especially drying of tomatoes.

Indirect methods require the development of small temperature differentials, which affects drying. The process is achieved by circulation of air directed through the drying trays to the products. Kordylas (1990) described drying process as being relatively cheap, very

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efficient for high moisture content food for discouraging actions of mould growth and concentrate food vitamins and flavour when dried. Etienne and Serge (1983) states that vegetable drying is facilitated by slicing and spreading out the product to increase their surface area to hot air; adopting a reliable heat medium; increasing the circulation of air around the product; insulating the areas that are not exposed to the same source of heat to avoid heat loss; avoiding direct heating since this affects the quality and appearance of the product; and protecting the dried products against contamination, re-absorption of moisture from the environment and harmful effect of sunlight.

Dryers are one of the most important equipment in food processing industries. Many dryers have been developed and used to dry agricultural products in order to improve their storage conditions (Mulhlbauer *et al.*, 1996). Most of the dryers use either expensive source of energy such as electricity (Berinyuy, 2000) or a combination of solar energy and other forms of energy. The most common dryers for vegetables are continuous tunnel dryers, vacuum dryers or solar dryers. Huber and Menners (1996) discovered that out of over 200 different types of dryers that have found different applications in industry, only about 20 basic types and their variants are commonly used in practice. This wide range is as a result of different physical forms of the products to be dried, desired rate of drying and quality constraints of the dried products. Most of these dryers are only seen in tertiary institution laboratories while the vegetable farmers especially in Nigeria do not have access to these dryers. Hence, these farmers suffer a lot of losses during peak periods of production. Many farmers usually abandon their vegetables in the farm due to low price, which is much less than the cost of production. Besides, vegetable traders also suffer a lot of losses due to poor storage facilities for their unsold vegetables. Direct sun-drying and the use of solar driers depend on the intensity of the sun energy to heat up the air and effect drying. Most vegetables are usually at the peak of their yield when the rain has fully set. This period is characterized by low sun energy and high relative humidity. This condition prolongs drying time which results to deterioration due to mould growth on the product.

Based on these, it is necessary to heat up the air using electricity, wood or fossil fuel to provide drying potential by reducing the air relative humidity so as to dry the product more effectively. This will add value to vegetables, encourage large scale production, reduce waste during harvest and stabilize price. Hence, the study will be of great benefit to vegetable farmers especially in the rural areas and help solve food security problems especially in developing countries such as Nigeria where, for example, 29,000 metric tonnes of tomato is wasted in three states of the North while Nigeria imports 26,000 metric tonnes of tomato paste annually (Mbi, 2008). Besides it can also be profitable to food processing industries for the production of dried tomatoes, okra, onions, pepper and carrots. This work is therefore aimed at reducing fruits and vegetable wastage and improving their storage conditions with the specific objectives of designing and developing a dryer using residual heat from wood to produce hot air, fabricating the dryer and testing the performance of the dryer.

Design and development considerations and analysis of the industrial fruit and vegetable dryer:

Design and Development Considerations: In designing and developing of the device, the following were considered;

- The energy required for the drying should be generated from locally available biomass energy sources such as wood, charcoal and other agricultural by-products
- Dryer chimney which permits quick escape of humid air from the drying chamber.
- The construction materials must be locally and easily available.
- The device should be able to separate smoke from the drying air to avoid altering the taste and colour of the drying material.
- The building technique of the device must be known to the local farmers or craftsmen.
- The drying chamber should be batch dryer and can be operated by one person.
- The stoker building should permit easy evacuation of the ashes.

Some Design and Development Analysis: The design of the industrial fruit and vegetable dryer (Figure 1) was analyzed in accordance with the following: Amount of moisture to be removed, quantity of air required to effect drying, volume of air to effect drying, blower design and capacity, quantity of heat required, heat transfer rate, actual heat used to effect drying, rate of mass transfer, thermal efficiency of the dryer and drying rate. The design was based on environmental temperature (T_1) of 31ºC, average relative humidity (Rh) of 35 %, initial humidity ratio (H_{r1}) of = 0.01 kg/kg dry air, safe drying temperature required in the dryer cabinet (T_2) of 50 ºC, tray size of 0.58 m x 58 m containing 43.1 kg of tomato resulting to capacity of the dryer (M) of 258.6kg/batch for the six trays.

(a): Amount of moisture to be removed in kg (M_R) is given in Equation (1) as:

$$M_R = M\left(\frac{Q_1 - Q_2}{1 - Q_2}\right) \qquad (1)$$

where, M is dryer capacity per batch (258.6kg), Q_1 = initial moisture content of the tomatoes to be dried (95.7%), Q_2 = maximum desired final moisture content based on experimental results (Ehiem, 2008) which is 28.08%. M_R is therefore determined to be 243.14kg.

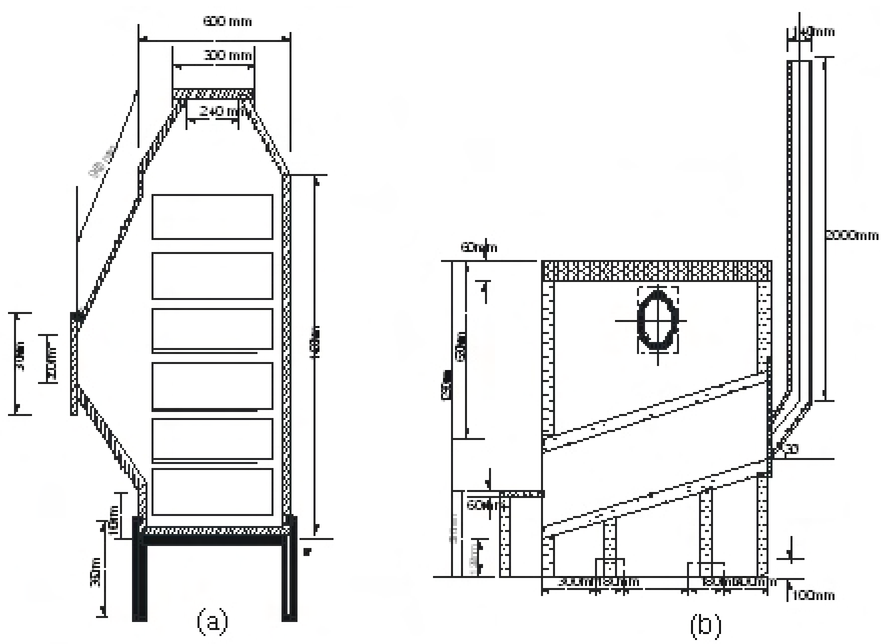

Fig. 1: Component parts of the dryer (a) cross section of dryer cabinet; (b) cross section of heat exchanger

(b): Quantity of air required to effect drying in kg (Q_a). This can be calculated as (Ajisegiri *et al.*, 2006):

$$Q_a = \frac{M_R}{H_{r2} - H_{r1}} \quad (2)$$

where, H_{r1} and H_{r2} are initial and final humidity ratios in kg/kg dry air respectively; and M_R is as determined in Eq. (1). The average ambient temperature and relative humidity are 31ºC for dry bulb temperature, 28 ºC for wet bulb temperature and 35% for relative humidity. The initial humidity ratio (H_{r1}) is determined to be 0.01 kg/kg dry air using the psychometric chart under normal temperature and 101.325kpa barometric pressure. After the heat has been supplied, the temperature of the product rises to 50 ºC giving the final humidity ratio (H_{r2}) as 0.028 kg/kg dry air. Substituting, the quantity of air required to effect drying (Q_a) is 13,507.78kg.

Volume of air to effect drying in m^3 (V_a) can be expressed as (Ajisegiri *et al.*, 2006):

$$V_a = \frac{Q_a}{r_a} \quad (3)$$

where, r_a is the density of air in kg/m^3 which is determined at 0 °C to be 1.115 kg/m^3 based on properties of common fluids presented by Cornwel, 1978. The volume of air to effect drying is therefore calculated to be 12,114.6 m^3.

Blower design and capacity: The blower serves the purpose of transferring heated air from the heat exchanger to the dryer cabinet. The selection was based on the characteristics of centrifugal fan performance curve based on the Equations (4) – (6):

$$N_2 = N_1\left(\frac{q_1^{1/2}}{H_1^{3/4}}\right)\left(\frac{H_2^{3/4}}{q_2^{1/2}}\right) \quad (4)$$

$$D_2 = D_1\left(\frac{H_1^{1/4}}{q_1^{1/2}}\right)\left(\frac{q_2^{1/2}}{H_2^{1/4}}\right) \quad (5)$$

$$hp_2 = hp_1\left(\frac{D_2^5}{D_1^5}\right)\left(\frac{N_2^3}{N_1^3}\right) \quad (6)$$

where N is the rpm of the electric motor, H is the static pressure (Pa), q is the volumetric flow rate of air (m^3/min), D is the diameter of the blower (m) and hp is the motor horse power. Based on the selection from the chart presented by Henderson and Perry (1976) on the performance curve of a backward-curved centrifugal fan showing system characteristics, N_1 is 1000 rpm, D_1 is 0.46m, H_1 is 1.41, H_2 is 1.09, q_1 is 226.4 m^3/min, q_2 is 198.1 m^3/min and hp_1 is 2.28. Based on Eq. (4), N_2 is determined to be 881.35 rpm for which an electric motor of 1000 rpm was selected. The value of D_2 was calculated to be 0.46m based on Eq. (5) while hp_2 was calculated from Eq. (6) to be 1.62 hp for which a 2 hp electric motor was selected.

The Blower Capacity (BC) is calculated as (Tyler, 1985):

$$BC = Q_a + Q_a\ (n) \tag{7}$$

where $Q_a = Q_m + R_e + Z_k$ and $Q_m = r_a \times q_2 = 1.115$ kg/m^3 x 198.1 m^3/min = 220.88 kg/min; R_e = 25% of Q_m which is 55.22 kg/min; Z_k = 1-2% of Q_m which is 4.42 kg/min at 2%; and n= percentage safety factor that ensures an adequate supply of air in all operating conditions at 15% but usually 10-20%. Substituting, BC is therefore calculated to be 322.6 kg/min.

Quantity of heat required to effect drying (H_r) in KJ is given by:

$$H_r = (M \times H_K) + (H_L \times M_R) \tag{8}$$

where M = dryer capacity per batch (258.6 kg); $H_K = C_T\ (T_2\text{-}T_1)$, whereas C_T is specific heat of tomatoes = 4.6 KJ/kg°C and T_2-T_1 = 50-31 = 19°C, the value is determined to be 87.4 KJ/kg; H_L = latent heat of vaporization = 1248.1 KJ/kg; and M_R = amount of moisture to be removed (kg) = 243.14 kg. Substituting, Hr = 326,064.67 KJ.

Heat transfer rate (Q_{ht}) can be determined (Cornwel, 1978) as:

$$Q_{ht} = hAT_B \tag{9}$$

where h = heat transfer coefficient = N_uK/d and with N_u (Nusselt) = 121.3 = $0.13R_a^{0.33}$ with $R_a = 10^9$; K as thermal conductivity = 0.0305KW/mK and d as diameter of the heat exchanger = 0.56m, the value of h is 6.607KW/m^2 °C; A = surface are of the heat exchanger = 0.7389 m^2; and T_B = temperature of hot air in the blower = 81 °C. The value of heat transfer rate (Q_{ht}) is therefore determined to be 395.43KJ

The quantity of heat that can be lost through the blower in the process is calculated as:

$$q_L = KAT_{BE}/\delta_k \tag{10}$$

where qL = quantity of heat lost (KJ); K = thermal conductivity of mild steel = 58 W/m.K; A = surface area of the blower = 0.88m^2; T_{BE} = temperature difference between the hot air in the blower and the environment = 81-31 = 50°C; and δ_k = distance =1. The value of q_L is therefore calculated to be 2.552KJ. The net heat transfer rate (Q_{htr}) that will reach the cabinet is ($Q_{ht} - q_L$) or (395.43-2.552) which is 392.89KJ. Oak red wood was used for generating heat for the dryer. Robert (1972) reported that 1 kg of oak red wood generates 22.9 KJ of heat. Hence, the quantity of firewood that will be required to generate 392.89KJ is 17.16kg.

Actual heat used to effect drying (H_D): The quantity of heat used in effecting drying H_D in KJ can be determined as in Eq. (11):

$$H_D = C_aT_c\ M_R \tag{11}$$

where C_a = specific heat capacity of air = 1.005 KJ/kg°C; M_R = amount of moisture to be removed = 243.14kg; and Tc = temperature difference in the dryer cabinet = 50-31 = 19°C. The quantity of heat is therefore calculated to be 4,642.76KJ.

Rate of mass transfer

The mass transfer rate Q_{mtr} in kg is determined by using Eq. (12):

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

where M_c = mass transfer coefficient of a free water surface = 0.083kg/m^{2}s; A_t = total surface area of the six trays = 0.3364m^2; ($H_{r2} - H_{r1}$) = (0.028 - 0.01) = 0.018 kg/kg dry air; and q_2 = air flow rate = 198.1 m^3/min. The mass transfer rate is therefore calculated to be 0.01kg.

Thermal efficiency of the dryer

The thermal efficiency of the dryer η_c is 84 % and is calculated based on Eq. (13):

$$\eta_c = H_D / Q_{ht}\ X t \tag{13}$$

where H_D = the quantity of heat used in effecting drying = 4,642.76KJ; Q_{ht} = heat transfer rate = 395.43KJ and t = drying time = 14 hours (Ehiem, 2008).

Drying rate: The calculation involving the design and analysis of dryers requires the knowledge of the length of time needed to dry a product from initial moisture content Q_1 to final moisture content Q_2 and the rate at which drying is taking place. These parameters were determined experimentally for a given material being dried (Ehiem, 2008). The rate and time of drying equations are expressed as (Ceankoplis, 1993):

$$R_c = \frac{M_d}{A_s}\frac{Q_1 - Q_2}{t} \tag{14}$$

where R_c= drying rate (Kg/mol); M_d= total weight of dried product = 122.2 kg; A_s = surface area of the dried solid = 0.3364m^2; t = drying time = 14 hours; Q_1 = initial moisture content = 95.7% w.b; and Q_2 = final moisture content = 28.08% w.b. The drying rate is therefore calculated to be 17.5 kg/mol. Drying time for different vegetables has been reported by Robert (1999). Ridwan *et al.* (1999) stated that the average drying rate of copra at constant rate period and falling rate period are 2% w.b/hr and 1.3 %, respectively. According to Oguntunde and Adejor (1992) drying rate increases with increasing temperature. Detailed discussion of drying rate curves are given by Keey (1991) and Mujumdar and Menon (1995). Drying rate are usually affected by heat, relative humidity, air circulation, size of food particles and capacity of the drier (Isabel *et al.*, 2000).

Fabrication, Assembly, Description and operation of the dryer: The main component parts of the dryer are: (a) Stoker, (b) Heat-exchanger, (c) Blower, (d) Chimney (e) Dryer Cabinet and Stands and (f) Trays. The components were fabricated, built and assembled according to design (Ehiem, 2008).

Choice of Materials: The materials used for the construction of the drier are easily maintained and repaired, and can be obtained locally at cheaper costs. The physical and chemical properties of the materials are strong enough to withstand heat, vibration, humid air, fatigue and stress without failure during operation. These include:

a) **Plywood:** This was chosen for the body of the cabinet because it is a poor conductor of heat. Hence, heat loss from the cabinet will be greatly minimized.
b) **Sheet metal (Aluminium):** It was chosen because of its high resistance to corrosion. The inside of the cabinet is lined with the sheet in order to reflect heat back to the cabinet and also prevent decaying of the wood due to humid air.
c) **Galvanized Sheet Metal:** This was chosen because of its toughness and ability to conduct and radiate heat. It was used for fabricating the heat exchanger.
d) **Mild Steel:** It has great strength and can be easily welded. It was used for the frame.
e) **Wire Mesh:** It was used for building the trays. This is due to its ability to resist corrosion and allow air to pass through it.
f) **Burnt Bricks:** This was chosen because it is a poor conductor of heat. It was used to build the wall of the heating unit.

Description of the Dryer: The dryer is made up of three sections; the heating, blower and drying cabinet sections (Figure 2).

The Heating Section: This was built of burnt bricks of 0.25m x 0.1m so as to minimize heat loss. It has two units (the stoker and heat exchanger) joined together with sand crete. The total area of their walls is 8.0368 m^2. This requires 333 pieces of burnt bricks blocks to build. The stoker is where fire is made and is 0.6m x 0.6m x 0.56m in length, width and height respectively. It has a loading opening area of 0.023m^2 which allows fuel and air to enter the stoker. A perforated sheet metal of 0.5m x 0.5m was placed 0.1m above the ground in the stoker to facilitate easy separation of the ash from the solid fuel (wood or charcoal). This arrangement encourages continuous burning of the fuel and easy collection of the ash. The exchanger is where air to the dryer picks up heat. It is 1.8m x 1.29m x 1.24m in length, width and height, respectively. The top is made of reinforced concrete of 1.8m x 1.29m x 0.02m. Inside are two 220 L oil drums welded together to form a single cylinder drum of the same length with the exchanger. This prevents smoke from having contact with the in-coming air to the dryer. The drum is also inclined at an angle of 5^0 and opened at both ends to allow smoke to pass freely from the stoker to the chimney by buoyancy force. At the down side of the exchanger length are four air inlets of 0.18m x 0.01m x 0.01m in length, width and height respectively, through which ambient air enters the heat exchanger. Towards the top side of one of the exchanger length is a 0.2 m

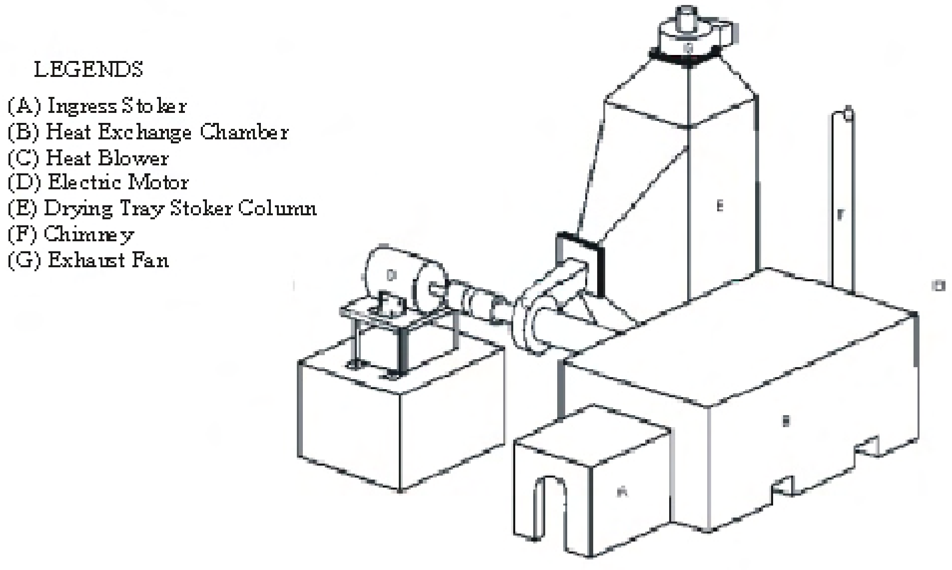

Fig. 2: The perspective view of the fruit and vegetable dryer: A – Ingress Stoker; B-Heat Exchange Chamber; C-Heat Blower; D-Electric Motor; E-Drying Tray Stalk Column; F-Chimney and G-Exhaust Fan

diameter opening through which hot air leaves the exchanger to the blower. The chimney was built of 2mm galvanized sheet metal of length 1.65 m and 0.14 m diameter. It has a total area of 0.61m^2. This encourages quick passage of smoke from the stoker to the atmosphere. The lower part has large flange so as to cover the drum opening and facilitate bolting it to the exchanger. The chimney channels the smoke from the stoker to the atmosphere.

The Blower Section: The blower is made of mild steel of 0.51 m in diameter and is linked to the exchanger with a cylindrical duct of 0.2 m diameter and 0.3 m long. The total area of the blower casing and the cylindrical duct was 0.88 m^2 which resulted to heat loss of 2.552 KJ to the surrounding. The ends of the duct are bolted to the blower and the exchanger air outlet. The blower air outlet is bolted to the diffuser. Its shaft is attached to the universal joint with a female end where the electric motor shaft is fitted. The universal joint ensures that the electric motor and the blower align.

The Dryer Cabinet: The dryer cabinet is made of 2″ plywood. It is of two sections (dryer and diffuser) joined together. The dryer contains the trays and is 0.6m x 0.6m x 1.45m in length, width and height giving a volume of 0.522 m^3. The inside is lined with aluminium sheet in order to prevent humid air removed from the drying product, from decaying the plywood and to reduce heat loss. The front and back sides are opened for the door and diffuser respectively, so as to ease loading of the trays and the hot air entering the dryer. The diffuser is like frustum in shape and is attached to the dryer. The base and the top dimensions are 1.25m x 0.6m and 0.24m x 0.12m, respectively. The latter is bolted to the blower air outlet. The diffuser helps to spread the hot air from the exchanger to the drying products, so that all the products will have contact with the hot air at the same time. The top of the dryer cabinet is frustum shaped also, so as to hasten the removal of humid air from the dryer, which may result to condensation. The cabinet stand is built of mild steel and is 0.61m x 0.61m in length and width, and 0.35 m above the ground. This helps to raise the cabinet above the ground to avoid decay and termite infestation. The tray frames and bodies are made of mild steel to make them strong for supporting the weight of the vegetables and wire mesh to ensure proper aeration of the drying product. Each tray is 0.58 m long, 0.58 m wide and 0.13 m high with a volume of 0.0437 and 0.262 m^3 for the six trays. The uniform gap of 0.1 m between trays is to prevent condensation and improve vaporisation process on the drying product.

Operational Considerations: The machine dries vegetables in batches. In the case of tomatoes, each batch takes about seven baskets in local measures with a basket weighing 34.16 kg on the average. The drum in the exchanger is heated conventionally by the heat generated in the stoker. Ambient air enters the exchanger through the exchanger air inlets, make contact with the heated drum and become hot. The blower sucks the hot air through a cylindrical duct bolted to blower and exchanger air exit, and sends it to the diffuser which spreads it evenly to the drying products. The suction fan on top of the cabinet sucks the humid air from the dryer and discharges it to the atmosphere.

MATERIALS AND METHODS

Performance test and evaluation: The materials used for testing of the machine include tomatoes, firewood, mercury-in-bulb thermometer, digital anemometer, hydrometer, tomato slicer, vernier calliper and weighing balance.

Heat Generation: The heat for the drying was generated by making fire in the stoker using firewood. To run the dryer per batch, 126.159, 129.676 and 134.599 kg of heat was generated for air flow rates of 18.3, 18.8 and 19.5 m/s, respectively.

Air flow rates: The air flow rates were obtained from a centrifugal fan driven by 1400 rpm electric motor. The air flow into the cabinet was reduced from the electric motor speed of 25 m/s to the three different speeds of 18.3, 18.8 and 19.5 m/s by introducing an electrical speed reducing device. These various speed levels were determined experimentally by placing a digital anemometer at the blower air outlet. The machine was run for 30 min to stabilize the environmental condition for the drying before introducing the products.

Temperature, relative humidity and moisture content measurements: The temperature of the drying chamber was measured using mercury-in-bulb thermometer, placed appropriately at three different points at regular intervals on one of the walls. The relative humidity was measured using hydrometer. Moisture content was measured using the standard oven method. The average initial moisture content of the tomatoes was 94.5 % w.b.

Size of tomatoes: The tomatoes used for the experiment were purchased from Wadata market, Makurdi, Benue State, Nigeria. The tomatoes were washed and characterised into three different sizes (large, medium and small) based on length and width measurements using vernier callipers. Two thousand grammes (2000 g) of each size were weighed and sliced along its length into four relatively equal parts and spread thinly in one layer on each drying tray in the cabinet. The weight of the sliced tomatoes was measured hourly using a weighing balance for 14 h when it is expected that no further appreciable loss in weight would be recorded. Each experiment was replicated six times.

Experimental design: The test was conducted using split plot in Randomized Complete Block Design (RCBD) with a total number of 756 observations (3 sizes x 3 air flow rates x 14 hours drying time x 6 replications). However, because of the effect of blocking, the replications usually disappear in the computations for analysis of Variance (ANOVA) as mean values are used instead.

RESULTS

The effect of size and air flow on drying of tomato slices is presented in Table 1 and Figure 3 while the analysis of variance (ANOVA) is summarized in Table 2. The analysis of variance shows highly significant size, air flow rate and drying time effect ($P \leq 0.01$) while interaction between size and air flow was found to be significant ($P \leq 0.05$).

DISCUSSION

Effect of size: For all the tomato sizes and at all air flow rate levels, gram weight of the tomato decreased with increase in drying time. For example, for small size and at air flow rate of 18.3m/s, gram weight decreased from 2000 g at 0 h drying time to 1548.2 g after one hour drying time to 101.7 g after 14 h of drying time. Also for all the sizes at all drying time levels, gram weight decreased with increase in air flow rate. For example, for medium size and at drying time of three hours, gram weight decreased from 1200 grams at 18.3m/s to 967.5 grams at air flow rate of 18.8 m/s and then to 794.3 grams at 18.8m/s. It's generally accepted that drying capacity increases with decrease in size. This view tends to be in line with the findings of the effect of size on the drying of tomatoes. The weight of tomato sizes decrease with increase in air flow rates and time. This is because the smaller the sizes of tomatoes the more the contact surface area with the air flow in the cabinet. This gives room for faster expulsion of evaporated moisture from the tomatoes within the cabinet. Hence, the smaller the sizes, the faster the decrease in weight with increase in air flow rate.

The analysis of variance (Table 2) shows highly significant size effect. A 2-tailed F-LSD test at the 5% level of significance at all fourteen time levels and three levels of air flow rate representing 42 mean comparisons shows that between small and medium sizes, 16.67% of the mean comparisons were non-significant. Similarly, 4.76% non-significance was observed in the mean comparisons between small and large sizes and 23.81% between medium and large sizes. The greater the non significance percentage difference, the closer the similarity between the sizes. The gram weights of the medium sizes were generally higher than those of the small sizes and those of the large sizes were generally higher than those of the medium sizes at all the drying times and air flow rates studied. At 18.3m/s and drying time of 7 hours, the grams weight for medium sizes was 458.3grams compared to 392 grams for small size; and 591.7 grams for large size compared with 458.3 grams for medium size. Similar trends were observed at all the

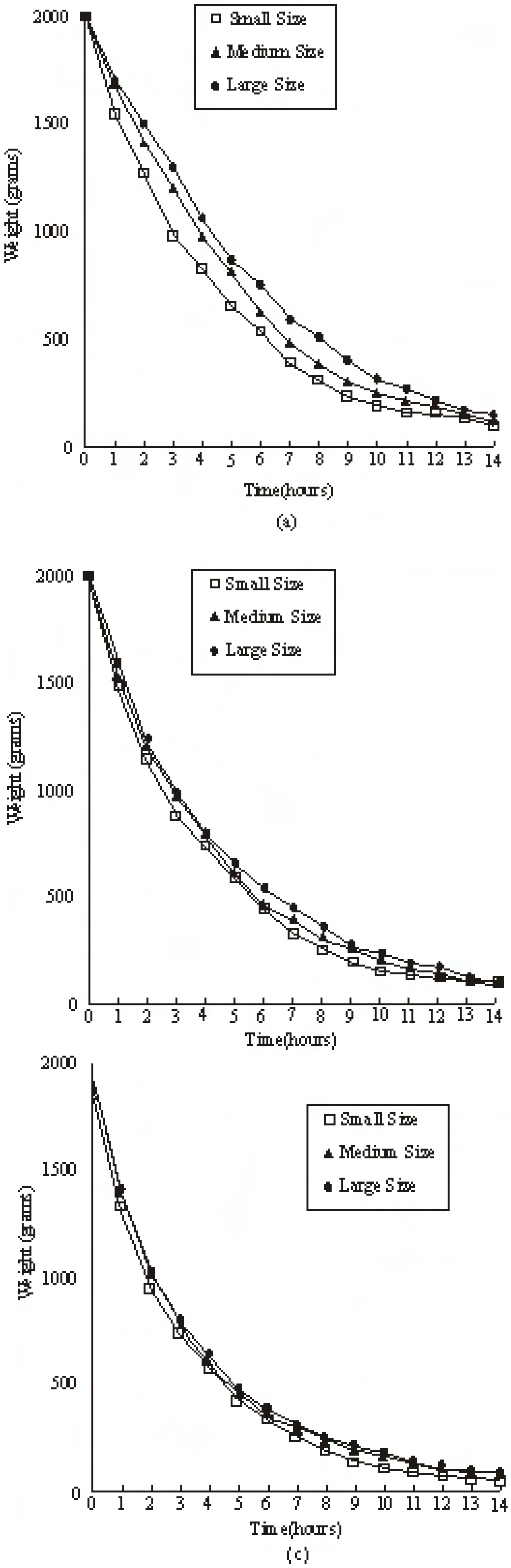

Fig. 3: Drying curves for different tomato sizes at different air flow rates (a) 18.3 m/s, (b) 18.8 m/s, and (c) 19.5 m/s

Table 1: Effect of size and air flow on drying of tomato slices as a function of time

		Drying time (hours)*														
Size	Air flow rate (m/s)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Small	18.3	2000	1548.2	1273.3	979.2	830.7	655.2	537.3	392.0	313.8	237.2	195.8	164.7	159.3	135.3	101.7
	18.8	2000	1483.3	1146.7	882.5	745.8	590.8	450	332.5	261.8	197	157.5	139.8	127.3	117.8	101
	19.5	2000	1391.7	990	773.3	595.8	441.7	357.5	268.3	194.0	145.8	120.0	97.7	77.5	62.0	50.5
Medium	18.3	2000	1681.3	1418.3	1200	976.8	813.3	630	458.3	385	301.7	250.5	212	192.5	153.8	120
	18.8	2000	1529.2	1206.3	967.5	795.8	614.2	462.5	395.3	314.1	256.2	202.7	165.7	146.2	123.5	109.2
	19.5	2000	1465.8	1077.2	794.3	631.7	473.3	366.7	310	249.5	208.5	160.7	139.2	112.8	86.7	63.5
Large	18.3	2000	1704.3	1500.8	1300.0	1066.7	870.5	752.5	591.7	508.3	412	317.3	270.8	214	172.5	150.2
	18.8	2000	1593.5	1240.0	989.5	803.3	661.8	545.3	453.7	364.7	278.3	237.7	195.7	176.8	127.8	110.3
	19.5	2000	1480.5	1069.3	843.3	668.5	504.7	399.3	330.0	267.2	222.3	182.3	141.3	119.2	101.8	89.5

*gram weight values are a mean of six replications, *Fishers Least Significant Difference (F-LSD),* F-LSD (P = 0.05) of the difference between two size means = 18.57, F-LSD (P = 0.05) of the difference between two air flow means = 26.06, F-LSD (P = 0.05) of the difference between two time means = 40.88

Table 2: Summary of ANOVA on effect of size and air flow on drying of tomato slices

Source of variation	Degrees of freedom	Weight (g)	5%	1%
Time	14	1624.31**	2.067	2.80
Size	2	53.49**	3.34	5.45
Error (a)	28			
Air flow	2	92.81**	3.118	4.904
Interaction (size and airflow)	4	2.72*	2.498	3.582
Error (b)	84			

**Highly significant ($P \leq 0.01$) *Significant ($P \leq 0.05$)

drying times and air flow rates studied. The non-significant difference of the various sizes was mainly at 13th and 14th hour level. This is due to reduced weight and surface area resulting from contraction of the pore spaces (shrinkage) in drying tomatoes. This agrees with the drying equation expressed by Ceankoplis (1993) for determining the drying rate of agricultural products. Again, the increase in weight with increase in size at constant air flow rate is due to the fact that the surface area in contact with the drying air is decreasing with increase in size of tomatoes.

Effect of air flow rate: The results show that as the airflow rate increased at constant drying time, the gram weight decreased. At drying time of four hours, the gram weight decreased from 830.7 grams to 595.8 grams for small size, 976.8 grams to 631.7 grams for medium size and 1066.7 grams to 668.5 grams for large sizes. The gram weight decreases with increase in air flow rate because the rate of expelling evaporated moisture and replacing drying air in the cabinet is faster with increase in air flow. Hence, vapour pressure difference are created at a faster rate with increase in air flow rate, which accelerate loss of weight in tomatoes. This is contrary to the findings of Treybal (1984) who stated that drying rate is not appreciably affected by air velocity; Hutchinson and Otten (1983) who worked on soybean and white beans showed that air flow rate of 0.25- 0.58 m/s and nominal velocity as low as 0.14 m/s for soybean and white beans respectively have no effect on drying rate; Henderson and Pabis (1962) who stated that for grains, the air flow rate becomes significant only at 0.102 m/s and below and Huskin and Schmidt (1960) and Chittenden and Hustrulid (1966) who reported that drying rate of various agricultural products are independent of air flow rate. This is because the agricultural product they worked on are of lower moisture content, microscopic pore spaces and higher concentration of dry matter when compared with ripe tomato fruits. For instance ripe tomato fruit is about 94.53% water (Musa-Makama, 2006) with less than 10% dry matter. Hence, the tendency of loosing its moisture to the surrounding is very high.

The analysis of variance (Table 2) shows highly significant air flow rate effect. A 2-tailed F-LSD test at the 5% level of significance shows that in the case of small size the 91 gram weight mean comparisons were found to be 6.59% statistically non significant at 18.3 m/s; 13.19% at 18.8 m/s and 7.69% at 19.5 m/s. In the case of medium size, non significance was observed in 4.4% out of the 91 mean comparisons at 18. 3 and 19.5 m/s; and 5.49% out of the 91 mean comparisons for 18.8 m/s were also found to be statistically non significant. However in the case of large size 1.1%, 3.3% and 6.6% non significant differences out of 91 mean comparisons were observed at air flow rates of 18.3, 18.8 and 19.5 m/s respectively. The non-significant differences observed in all the flow rate at various sizes are at 13th and 14th hour levels. The gram weights at all the flow rates are small at these levels. This is due to the fact that the moisture in tomatoes are tightly held by the dry matters resulting to little moisture evaporation from the tomatoes. Hence, no appreciable differences are observed in the weight lost of the tomatoes at these levels. This is in line with the report of Treybal (1984), Huskill and Schmidt (1960) and Chittenden and Hustrulid (1966) that drying rate is independent of air flow rate. This is due to the fact that, at this hour levels, the concentrations of dry matters, water contents and pore spaces in drying tomatoes are relatively similar to the products they studied.

Effect of drying time: The results show that the gram weight of all the samples decreased with increase in drying time at constant airflow rate. For drying time range of zero to 14 hours at constant airflow rate of 19.5 m/s, gram weight of small size decreased from 2000 grams to 50.5 grams, medium size from 2000 grams to 63.5 grams, and large size deceased from 2000grams to 89.5 grams. The decrease in weight with increase in time for all the flow rate is due to the fact that the drying time depends on the weights (water contents) of the product to be dried. The more the weight, the longer time required to reduce it at constant temperature. For tomatoes, the difference between the initial weights (water contents) and the desired weight is very high, requiring longer time to reduce. This is because as drying is going on, the tomato pore spaces are contracting with high concentration of dry matters resulting to low evaporation of moisture with time. This is in line with the drying time equation described by Ceankoplis (1993) where it can be observed that the higher the weight the more the time it takes to carry out drying.

The analysis of variance (Table 2) shows highly significant drying time effect. A 2-tailed F-LSD test at the 5% level of significance indicates that the gram weights were found to be statistically different at all drying time levels for small and large sizes except at drying time levels of 13 and 14 hours where non significance was observed in one each out of three mean comparisons respectively. For the medium size, statistical difference was observed at all drying time levels except at drying time of 14 hours where one non significance difference was observed. The non-significant differences observed at 13th and 14th hour levels are as result of the reducing weight of the dry tomatoes, which resulted from moisture removed. This equally agrees with the Ceankoplis (1993) drying equation in that, as the weight is decreasing, the time of drying tends to zero.

CONCLUSION

A fruit and vegetable–drying device was designed and developed using low price materials that can easily be assessed and maintained by vegetable farmers. The device has a mean thermal efficiency of 82% with average capacity of 258.64 g/batch. The average drying rate of the device is 40 g/h.

The size, air flow rate and drying time have highly significant ($P \leq 0.01$) effect on gram weight of the tomato slices being dried. For all the tomato sizes and at all air flow rate levels, gram weight of the tomato decreased with increase in drying time. Also for all the sizes at all drying time levels, gram weight decreased with increase in air flow rate.

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