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Design of a Multipurpose Dryer

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Abstract:
Drying is one of the most important processes involved in the post-harvest handling and processing of agricultural product. A multipurpose dryer is designed to handle a variety of product ranging from grains, fruits vegetable to animal products like meat, fish etc. The criteria considered in the design computation and selection of materials includes; technical simplicity and ease of operation, profitability, durability. The dryer consists of a heating chamber incorporated with a heat exchanger, suction unit and drying chamber with a rotary shaft to induce rotation of the tray. In operation, the heating chamber is filled with water and incorporated with a heater and coiled copper tubing that are directly linked with the suction unit. The suction unit draws air into the copper tubing, the air passing through this chamber gains heat through the heated water via the copper tubing as a result of conduction. The air is then conveyed directly to the drying chamber. In the drying chamber, hot air absorbs and conveys moisture from the substances needed to be dried by heat and mass transfer as well as diffusion process, while the residual air is discharged through the vent on top of the chamber. Variable parameters needed for design include; weight/mass of moisture to be removed, quality of air required to remove the moisture, amount of heat needed by drying air, maximum amount of heat that can be gained by water from the heater and, the amount of heat which air can absorb from heated water.

Keywords: *Heater, water, dryer, food product, fan and pump.*

1. Introduction

Drying is one of the most commonly used methods of preserving bio-resources and agricultural products and thereby preventing spoilage and wastage with the aim of prolonging their shelf-life. The process is governed by a heat and mass transfer phenomenon, whereby, due to the application of heat energy, moisture movement from the inner part of the substance to the surface is enhanced where it is finally evaporated by diffusion. It is a continuous process with simultaneous changes in moisture content, product temperature and humidity. It involves; heat and mass transfer between the surface of the substance and surrounding medium and the transfer of heat and matter within the substance.

Need for Preservation: Agricultural products after been harvested, usually exhibit a very short shelf life of few hours to few days due to their water content, which in conjunction with the environment, inevitably enhance microbial activities and leads to spoilage of the product and eventual wastage of bio-resources, energy and time. The call for an adequate preservation method has always been a problem in time past and even now to handle. Food which is a necessity for survival for man and livestock has to be available at all time for the proper functioning of the entire metabolic processes of an active human being/livestock. Also, due to the very fact that must crops cultivated and animal production is often affected by season, the preservation measures cannot be done without an adequate and efficient preservation technique, which must be employed to ensure availability of seasonal agricultural products after harvesting operation and beyond. This has led to the employment of many preservation techniques broadly classified into two groups viz: local and modern preservation techniques.

1.1. Problem Statement

More than 80% content of most fruits, 75% content of vegetables, and 45% content of animal product is water (GEPC, 2005). Micro-organisms can obtain nutrients and water for their growth from the bio-resources in which they grow. Hence, the substance must be dried in order to stop the multiplication of micro-organisms and to ensure the storage of the food item for a longer period, increasing its shelf-life.

Traditional open sun drying is a common and widely used method for drying of agricultural produce including fruits, vegetables, cash crops, fish and meat. It is the simplest way of drying foods by direct exposure of the product to the sun. Even though sun drying is the cheapest method, the quality of the dried product is far below standards. This method has some disadvantages including contamination, microbial discoloration, browning and damage by birds or insects and slow or intermittent drying.
Dried product quality improvement and reduction of losses can be achieved by the introduction of suitable drying technologies such as a solar drying technique or artificial drying technique utilizing electric power and an artificial air ventilation system. However, most solar dryers that are constructed use only solar energy as a heat source for drying. This makes the solar dryer to be dependent on climatic conditions limiting its use in cloudy periods and at night. As a result, agricultural produce that are harvested in the rainy season are still subjected to spoilage.

1.2. Justification

Dried fruits, vegetables, meat and fish are easily conveyed in large quantity due to the massive reduction in their total weight as result of the removal of water. Dried food has considerably shown a high increase in their nutritional value relative to their dry state total weight. Dried fruit is mainly consumed as a snack and as an ingredient for breakfast cereals, healthy ready-to-eat snacks and desserts. Breakfast cereal mixtures and bakeries are one of the largest end users of dried fruit. A promising steady power generation for our country Nigeria is also a great motivation for this research and development of this 100% electric power depending device.

1.3. Objectives

1.3.1 To prevent product quality deterioration and loses that help farmers for food security and improve livelihood
1.3.2 To achieve drying efficiency comparable to that achieved by highly sophisticated machines.
1.3.3 To design a machine that would be made from locally available materials.
1.3.4 To achieve an appropriate technology i.e. highly trained personal should not be a necessity for operation of this device.
1.3.5 To eliminate charring of product
1.3.6 To avoid browning/surface hardening of product.
1.3.7 To prolong the shelf-life of agricultural product without effect on its texture, flavour and nutritional value
1.3.8 To design an effective drying machine capable of operating at any environmental condition.

2. Drying Techniques

2.1. Sun Drying

Brenndorfer *et al.* (1987) defines sun drying as the spreading of a produce to the sun on a flat surface. In sun drying, the product is heated directly by the sun's rays and moisture is removed by natural circulation of air. The process of sun drying does not require any other source of energy except sunlight which makes it the cheapest method (Hii *et al*., 2012).
Even though sun drying is the earliest and commonest method of drying agricultural produce, it is labour and time intensive and also requires a lot of space per unit of the product. The product will absorb only a portion of the sun's energy while the remaining radiation is reflected. Additionally, wind blowing on the surface results in heat loss which can introduce moisture (Schiavone, 2011). During sun drying the agricultural product can be rewetted, especially at night when the ambient temperature is decreasing causing an increase in the humidity (Weiss and Buchinger, 2002).
Traditional open sun drying has many limitations. Intermittent and irregular loss of moisture and lower rate of drying increases the risk of spoilage during the process of drying. Due to high relative humidity and low air temperature, the final moisture content of the dried produce may be high enough to result in spoilage during storage (Brenndorfer *et al.*, 1987). Sun drying can lead to quantity and quality losses of the dried product. The losses can be associated with contamination by dust, dirt and infestation by rodents, insects and animals (El-Sebaii and Shalaby, 2012).

2.2. Solar Drying

Solar drying is a viable option to open sun drying. Solar dryers can increase the drying temperature and reduce relative humidity resulting in lower moisture content of dried product. Unlike sun drying, a solar dryer constitutes a specialized structure that controls the drying process and protects the produce from damage by dust, rain and insects (Raju *et al.*, 2013). Since the products are protected and the drying time is reduced significantly, the quality of dried product obtained by solar drying is better than that of sun drying (Seveda, 2013).
Solar dryers include; Direct solar dryers, indirect solar dryers, mixed mode solar dryers, hybrid solar dryers and solar dryers with concentrators

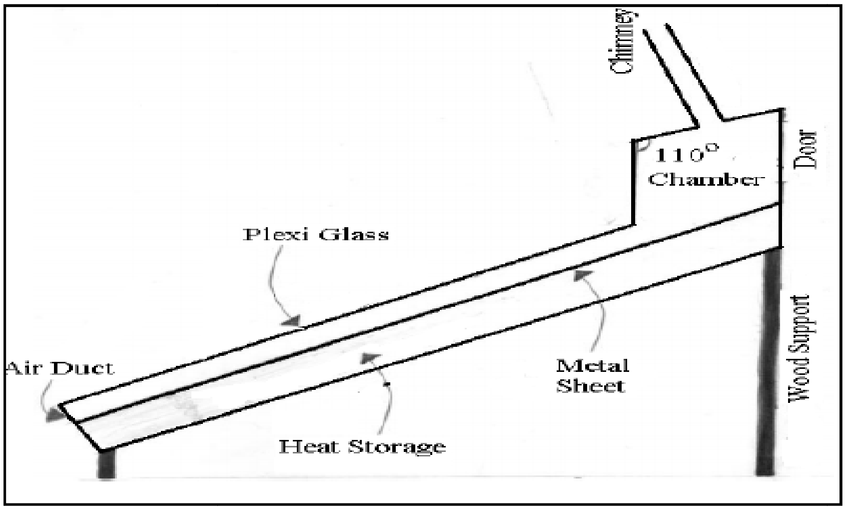

Figure 1: Indirect solar drying (Svenneling, 2012)

3. Material and Methods

3.1 Design consideration: The following are the criteria for this design;

3.1.1 Overall heat transfer co-efficient is the heat transfer coefficient of air.

3.1.2 Heat gained by air equal heat transfer to food substance.

3.1.3 Rate of vaporization equal rate of drying.

3.1.4 The dryer design was purely based on transfer coefficient of air and flow rate of air.

3.2 Components of the multipurpose dryer: The dryer consists of four main component, they are; the heating/heat exchange chamber, the suction air pump, drying chamber, a ventilating fan, and a vent.

3.2.1 Heating/heat exchanging chamber: it will be a closed chamber incorporated with heater and coiled copper tubing for passing air. This chamber shall be filled with water which will be the intermediate heating medium between the heater and air passing through the copper tubing.

3.2.2 Suction unit: this unit shall consist of an air pump capable of drawing air from the outside via the copper tubing to the drying chamber (it will be responsible for the increase flow rate of the incoming air.

3.2.3 Drying chamber: this chamber shall be closed during operation and will be the housing for whatever shall be dried.

3.2.4 Regulating fan: this shall be installed at the bottom of the drying chamber and shall work only when instructed to do so from the thermostat. The fan will be the temperature regulating device for the drying chamber. It will be turned on when d limit of temperature set out for drying is exceeded.

3.2.5 Vent: it will solely be responsible for the proper and adequate ventilation of the drying chamber to avoid unnecessary pressure build up in this chamber.

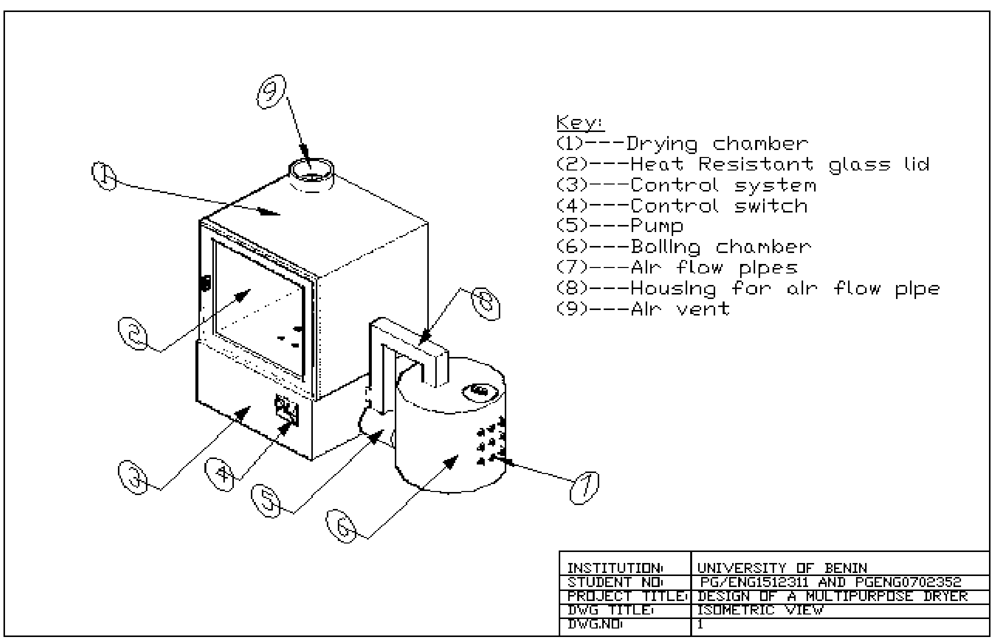

Figure 3: Isometric drawing of the Multipurpose dryer design

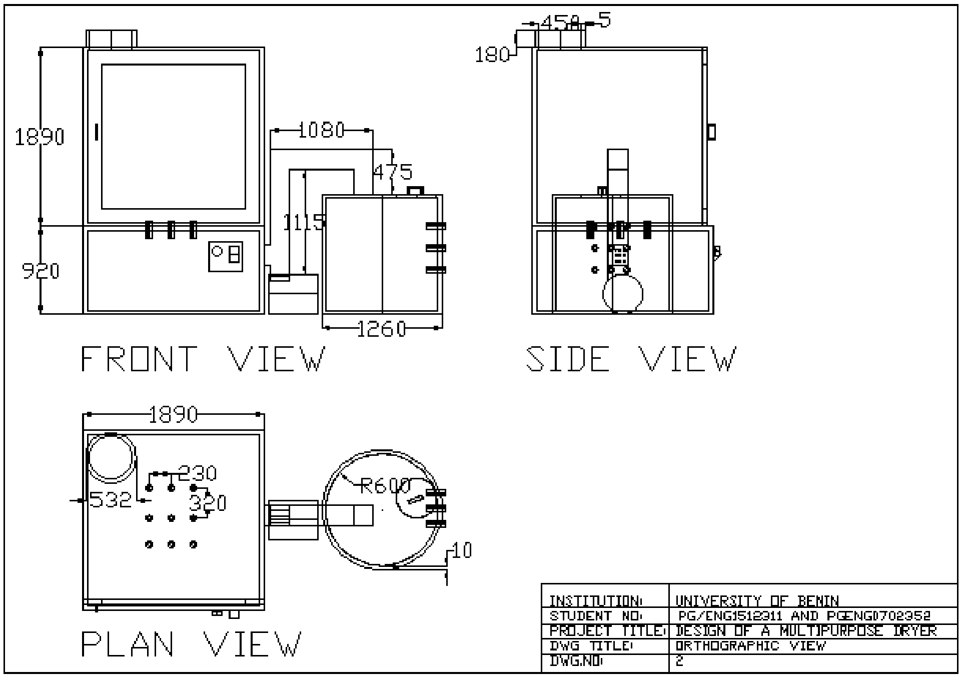

Figure 4: Orthographic drawing of the Multipurpose dryer design

3.3. Performance Evaluation of Dryer

3.3.1. Maximum heat water can attain in the heater chamber is;

$heatenergy, H = Mw \times c_w \times (T_W^f - T_W^i)$

Where;

$Mw --- Massofwater(kg)$,

$c_w --- specificcapacityofwater$((4200J/kg/k)

$T_W^f - T_W^i --- max.temperaturechangeofwater$,

$T_W^f ----boilingtemperatureofwater(100℃)$,$T_W^i ----roomtemperatureofwater(℃)$

3.3.2. Heat Exchanger Efficiency

$$heatexchangeefficiency = \frac{Maximumheatabsorbedbypassingair}{maximumheatwatercanabsorbfromheater} \times 100(\%)$$

$Maximumheatabsorbedbypassingair = Q \times \rho \times t \times C_p \times (T_f - T_i)]$

Where;

$Q ----- volumeflowrateofair(\frac{m3}{s}), \rho ------- densityofair(\frac{kg}{m3})$

$t ----durationofdrying(s)$

$C_p ----- specificheatcapacityofairatconstantpressure(\frac{J}{kg℃})$

$T_f ----- inlettemperatureofair(℃), T_i ----outlettemperatueofair(℃)$.

3.3.3. Drying Efficiency

Drying efficiency is the ratio of the energy needed to evaporate moisture from the material to the energy supplied to the drying chamber by air. This term is used to measure the overall effectiveness of a drying system.

$$dryingefficieny\ \% = \frac{energyassociatedwiththevaporisationofmoisture}{maximumenergydryingaircanattain}$$

$Energyassociatedwiththevaporisationofmoisture = M_{ew} \times L$

$Maximumenergydryingaircanattain = Q \times \rho \times t \times C_p \times [T_f + (T_f - T_i)]$

Where;

$M_{ew} - massofmaoistureevaporatedinkg$,

$L --latentheatofvaporizationofwaterin\ (\frac{J}{K})$

3.3.4. Drying Rate

Drying rate is the amount of evaporated moisture over time.

$$dryingrate = \frac{massofremovedmoisture}{timeofdrying}$$

$$dryingrate = (M_i - M_f)/t$$

Where;

$massofremovedmoisture = M_i - M_f$,

$t --- durationofdrying(S)$

$M_i --- initialmassofsample(kg)$, $M_f --- massafterdrying(kg)$

3.3.5. Moisture Content

Moisture content is one of the important parameters that is taken to evaluate the performance of a dryer. Moisture content of a material can be given either on the basis of total weight of the material to be dried or the amount of solid weight present in the material. The moisture content on wet basis is given by the following equation (Fudholi *et al.*, 2011):

$$moisturecontent(wetbasis)\%, M_{cw} = \frac{W_i - W_f}{W_i} \times 100$$

$W_i --- initialweightofsampleorwetweight(kg)$

$W_f --- weightafterdryingordryweight(kg)$

3.3.6. Drying Temperature

Scanlin, (1997) recommended drying temperatures for fruits and vegetables to be between 38- 58℃, and for fish and meat to be between 43-63℃. Higher temperature may cause sugar caramelization (browning of sugar) of many fruit products when drying and surface hardening in the case of fish and meat leading to a moister interior that could still provide the environment needed for microbial activities. Hence, for designing the dryer, average drying temperature, T_d, of 52.5°Cwas considered.

3.3.7. Amount of Moisture to be Removed

The formula to calculate the total amount of moisture to be removed (M_{ew}) is given by Bassey and Schmidt (1987) as:

$$M_{ew} = \frac{M_i(M_{CW} - M_{CD})}{1 - M_{CD}}$$

Where:

$M_i --- initialwetofsample$

$M_{ew} --- amountofmoisturetoberemoved$

$M_{CW} --- moisturecontent\ (wetbasis)$

$M_{CD} --- moisturecontent(drybasis)$

3.3.8. Air Flow Requirement

Scanlin (1997) recommends the range for air velocity(V_a) to be between 0.51 m/s to 5.08 m/s. Higher values of air flow rate may cause surface hardening in the case of food substances leading to a moister interior that could still provide the environment needed for microbial activities.

Air flow rate,Q_a= air velocity(V_a) ×cross sectional area of copper tubing opening(A_c)

$$Q_a = V_a \times A_c$$

3.3.9. Copper Tubing Selection

Nominal Size inches	Outside Diameter	Inside Diameter	Wall Thickness	Calculated Values (based on nominal dimensions)				
				Area of Bore, sq inches	Weight of Tube Only, pounds/linear ft	Cross Weigh tof Tube & Water, pounds/linear ft	Contents of Tube per linear ft	
							Cu ft	Gal
1/4	.375	.305	.035	.073	.145	.177	.00051	.00379
3/8	.500	.402	.049	.127	.269	.324	.00088	.00660
1/2	.625	.527	.049	.218	.344	.438	.00151	.0113
5/8	.750	.652	.049	.334	.418	.562	.00232	.0174
3/4	.875	.745	.065	.436	.641	.829	.00303	.0227
1	1.125	.995	.065	.778	.839	1.18	.00540	.0404
1 1/4	1.375	1.245	.065	1.22	1.04	1.57	.00847	.0634
1 1/2	1.625	1.481	.072	1.72	1.36	2.10	.0119	.0894

Table 1: Dimensions and Physical size of copper tube: Type K (http://www.engineeringtoolbox.com/astm-copper-tubes-d_779.html)

A copper tubing of type K with a nominal size of ½ inches, internal diameter of 0.527inches = 13.39cm, and cross-sectional area of 0.218inch squared = 0.00014064meter squared is chosen for this design.
The chosen air flow velocity and cross-sectional area of copper tubing to be 5m/s and 0.00014064m2.

$$Q_a = 9 \times 5 \times 0.00014064$$
$$Q_a = 0.0063288 \frac{m^3}{s}$$

3.3.10. Typical Sample Calculation Sheet

	Mango	Pineapple
Mass of mango before drying	100g	100g
Mass of contained water	85g	90g
% moisture content before drying	85%	90%
% moisture content after 200mins	15%	16.5%
Mass of water removed	(85-15) = 70g	90 – 16.5 = 79.5g

Table 2: A typical calculation sheet with assumed data for Mango and Pineapple fruits

Given the above assumed data for mango and pineapple, the following is obtained;

→ Drying rate;
Drying rate is the amount of evaporated moisture over time.

$$dryingrate = \frac{massofremovedmoisture}{timeofdrying}$$
$$dryingrate = (M_i - M_f)/t$$

Where;
$massofremovedmoisture = M_i - M_f, t --- durationofdrying(S)$

$$M_i --- initialmassofsample(kg), \quad M_f --- massafterdrying(kg)$$

→ For mango

$$dryingrate = (85 - 15)/200$$
$$dryingrate = 0.35g/min = 21g/hr$$

→ For pineapple

$$dryingrate = (90 - 16.5)/200$$
$$dryingrate = 0.3675g/mins$$

4. Conclusion

A multipurpose dryer was designed and it is recommended to be constructed from materials readily available in the market. Its simplicity in design makes it very easy to operate and maintain. The addition of a cooling fan makes the drying temperature suitable for all range of agricultural products and bio-resources No load testing, load testing with pineapple and mango were can be carried out using the dryer. The result would justify the dryer's ability to dry sliced fruits in few hours, which would be far quicker than a solar dryer or drying with the sun.

The multipurpose dryer could successfully reduce the moisture content of the substances tested to a level that is safe for storage.

5. Recommendation

The performance of the dryer can further be enhanced by making modifications and following the recommendations given below:

- A back up power source in the event of power failure.
- An alternative and cheap source of power (e.g.solar)
- A modified controlling system to maintain drying temperature at steady level

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