Design and Fabrication of Tray-Type Semi-Continuous Tunnel Dryer

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ABSTRACT

A tray type semi-continuous tunnel dryer for Agro-product was designed and fabricated to enhance proper and efficient drying of agricultural products (e.g. cassava chips) in large scale for preservation and export. The overriding considerations in the design were the nature and concentration of the feed, temperature range, air flow rate, discharge as well as the cost of materials. Design calculations assumed steady state considerations and most properties of the system were the values at standard temperature and pressure. Hot air is used as the heating and mass transfer medium in the tunnel. The hot-air generated by a heat exchanger is pumped to the tunnel by an electrically driven blower. Experimental results show that the optimum conditions for drying of cassava (used as a case study) require an inlet hot air temperature of 55-60°C and a residence time of 200-420minutes A reduction of the average moisture content to 6-5% at an equilibrium relative humidity of below 60% was considered as dryness and readiness for storage. This dryer is basically a group of truck-and-tray batch dryers, operated in a programmed series so as to be quasi-continuous. This machine is made up of a tunnel of 12m x 1m x1.2m in size with rails, 98 loading tray of 0.84m x 0.82m x 0.02m in size, heat exchanger, transmission duct, hot air blower, 4kw geared electric motor 38-178 output rpm, temperature gauge(three in number). The capacity of the machine is 300kg per full load (3kg per tray) in 3hrs 50min (relative).

Keywords: cassava chips, Heat transfer, Moisture content, equilibrium relative humidity, air flow rate.

INTRODUCTION

Drying is the oldest and an excellent simple way to preserve food. It is indispensable in food processing especially in northern part of Africa with its peculiar drying-friendly climatic conditions. Food can be dried in several ways, for example, by the sun if the air is hot and dry, or in an oven or dryer if the climate is humid.

However, the problem of appropriate drying is a critical driver for the development of agro- enterprise in Africa, most especially the rural sector. Over time, it was observed that various drying technologies especially sun and solar, have been explored and recurring challenges have always been cost viability, efficiency, effectiveness and durability. Recent interventions have focused on the use of mechanical dryers but this again is limited by irregular power supply, lack of local capacities to fabricate and manage it, and unaffordable initial equipment cost especially by the micro -processors and small to medium enterprise

Drying is perhaps the oldest, most common and most diverse of chemical engineering unit operations. Over four hundred types of dryers have been reported in the literature while over one hundred distinct types are commonly available. Energy consumption in drying ranges from a low value of under five percent for the chemical process industries to thirty five percent for the papermaking operations.

Drying occurs by effecting vaporization of the liquid by supplying heat to the wet feedstock. Heat may be supplied by convection (direct dryers), by conduction (contact or indirect dryers), radiation or volumetrically by placing the wet material in a microwave or radio frequency electromagnetic field. Over 85 percent of industrial dryers are of the convective type with hot air or direct combustion gases as the drying medium. Over 99 percent of the applications involve removal of water.

This is one of the most energy-intensive unit operations due to the high latent heat of vaporization and the inherent inefficiency of using hot air as the (most common) drying medium. A tunnel dryer is basically a group of truck-and-tray batch dryers, operated in a programmed series so as to be quasi-continuous. Truckloads of freshly prepared material are moved at intervals into one end of the long, closely fitting enclosure, the whole string of trucks is periodically advanced a step, and the dried truckloads are removed at the other end of the tunnel. The hot drying of air is supplied to the tunnel in any of several different ways, known as the counter flow, concurrent or parallel-flow, centre exhaust, multistage, and compartment arrangements.

This ability to dry large quantities of food in a relatively short time (2-6 h) made tunnel drying widely used. However, the method has now been largely superseded by conveyor drying and fluidised-bed drying, as a result of their higher energy efficiency, reduced labour costs and better product quality.

LITERATURE REVIEW

Drying methods and processes can be classified in several different ways. It can be classified as batch, where the material is inserted into the drying equipment and drying proceeds for a given period of time, or as continuous, where the material is continuously added to the dryer and dried material continuously removed.

Drying processes can also be categorised according to the physical conditions used to add heat and remove water vapour:
(1) In the first category, heat is added by direct contact with heated air at atmospheric pressure, and the water vapour formed is removed by the air
(2) In vacuum drying, the evaporation of water proceeds more rapidly at low pressures, and the heat is added indirectly by contact with a metal wall or by radiation (low temperatures can also be used under vacuum for certain materials that may discolour or decompose at higher temperatures) and
(3) In freeze drying, water is sublimed from the frozen material. Dryers expose the solids to a hot surface with which the solid is in contact. Dryers, which expose the solids to a hot gas, are called adiabatic or direct dryers; those in which heat is transferred from an external medium are known as non-adiabatic or indirect dryers. Dryers heated by dielectric, radiant, or microwave energy are also non-adiabatic. Some

units combine adiabatic and non-adiabatic drying; they are known as direct-indirect dryers.

Most commercial dryers are insulated to reduce heat losses, and they re-circulate hot air to save energy. Many designs have energy-saving devices, which recover heat from the exhaust air or automatically control the air humidity. Computer control of dryers is increasingly sophisticated and also results in important savings in energy.

Bin Dryer is a cylindrical or rectangular container fitted with a mesh base. Hot air passes up through a bed of food at relatively low speeds (for example 0.5 m3s-1 per square metre of bin area). This dryer have a high capacity and low capital running costs. Bin dryers are used, particularly for piece-form vegetable products, to complete the drying operation after most of the moisture has been removed in a tunnel dryer or the equivalent. Typically, they reduce the moisture content of a partially dried, 10 to 15% moisture cut vegetables to 3 to 6% or even lower in the case of onion slices and possibly cabbage shreds. Bin dryers improve the operating capacity of initial dryers by taking the food when it is in the falling rate period, when moisture removal is most time consuming.

Cabinet Dryer consists of an insulated cabinet fitted with shallow mesh or perforated trays, each of which contains a thin (2-6 cm deep) layer of food. Hot air circulated through the cabinet at 0.5-5 ms-1 per square metre tray area. Fresh air enters the cabinet, is drawn by the fan through the heater coils, and is then blown across the food trays to exhaust.

Pneumatic conveying dryers are those in which powders or granular materials are dried while suspended in a stream of heated air. In such dryers, powders or particulate foods are continuously dried in vertical or horizontal metal ducts. A cyclone separator is used to remove the dried product. Since the material entering this kind of dryer must be conveyable in an air stream, the incoming material must have been dried in other ways to a moisture level below 35-40 %.

Fluidised Bed Dryer is an entirely different kind of pneumatic conveying dryer. Fluid-bed drying permits continuous, large-scale drying of foods without over drying. The high heat transfer rates make it an economical process, and the lack of mechanical parts ensures low maintenance costs. The rapid mixing in the bed provides nearly isothermal drying conditions.

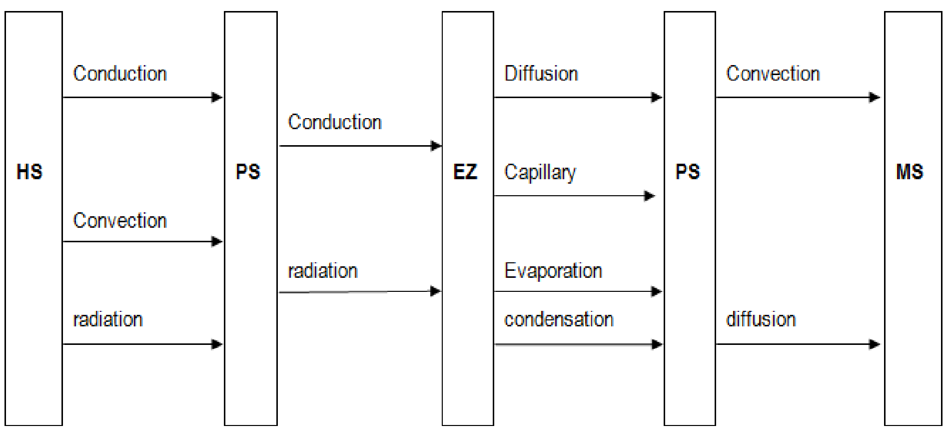
Kiln Dryer is two-storey buildings in which a drying room with a slatted floor is located above a furnace. Hot air and the products of combustion from the furnace pass through a beds of food up to 20 cm deep. The fruit is dried as a batch, but operates periodically enter the kiln and use hand scoops to turn and mix the partly dry product. The traditional kiln relies upon natural draft to provide sufficient circulation of air up through the moist material, but more modern units are provided with a mechanical exhaust fan in the space above the drying floor. If fuel oil is used for heating, the furnace is provided with an extensive array of sheet iron flues to transfer heat to the drying air.

Rotary Dryers is a slightly inclined rotating metal cylinder fitted internally with flights to cause the food to cascade through a stream of hot air as it moves through the dryer. Airflow may be parallel or counter-current. The agitation of the food and the large area of food exposed to the air produce high drying rates and a uniformity dried product. The method is especially suitable for foods that tend to mat or stick together in belt or tray dryers. However, the damage caused by impacts and abrasions in the dryer restrict this method to relatively few foods (e.g. sugar crystals and cocoa beans).

Drum Dryer (Roller Dryer) is a slowly rotating hollow steel drums are heated internally by pressurised steam to 120-170 °C. A thin layer of food is spread uniformly over the outer surface by dipping, by spraying, by spreading or by auxiliary feed rollers. Before the drum has completed 1 rev (within 20 s-3 min), the dried food is scraped off by a 'doctor' blade, which contacts the drum surface uniformly along its length. The capacity of a drum dryer is a function of the drying rate of the thin layer of material and the amount of product that adheres to the drum surface. The drying rate depends on the type of feed device, steam pressure within the drum, and the drum speed.

THEORETICAL BACKGROUND

The representation of a drying process can be compared to a network of electrical resistance each possible transport mechanism being an individual resistor. Thus for mechanisms in parallel we add the resistance reciprocally and for those that operate in series we add all the resistance directly. The diagram below illustrates the various mechanisms of heat transfer



Electrical analogy illustration

Where:

HS	=	Heat Source
PS	=	Piece Surface
EZ	=	Evaporation Zone
MS	=	Moisture Sink

It is widely accepted that fungi activity is negligible at ERH (equilibrium relative humidity) below 6% therefore material with ≤ 6% moisture content after drying operation could be considered dry and ready for storage (six months to a year) .In drying of cassava chips, regression analysis and modelling has shown that it is suitable to dry at 55-60 ^{O}C for 100-300 minutes so as to have perfect dehydration without gelling . Drying of moist solids is a common situation involving simultaneous inter- phase heat and mass transfer.

DESCRIPTION OF THE MACHINE AND OPERATION

This dryer is basically rectangular shaped tunnel of12mx1.2mx1.0m with rails on which the trays loaded with materials staged slide intermittently. The tunnel is attached to a heat source (heat exchanger fed with coal or wood) via a blower that conveys the hot air for drying. The blower is driven by a geared electric motor that is also used to vary the flow rate of hot air and the temperature is measured by two radial thermometer mounted on top of the tunnel. The temperature is controlled air inlet vent on the blower which allows in fresh air.

The operation is in a programmed series of quasi-continuous method. Loads of freshly prepared materials on trays are loaded inside the tunnel along the rails and moved at intervals through one end of the long tunnel, the whole string of loads is periodically advanced a step, and the dried loads are removed at the other end of the tunnel.

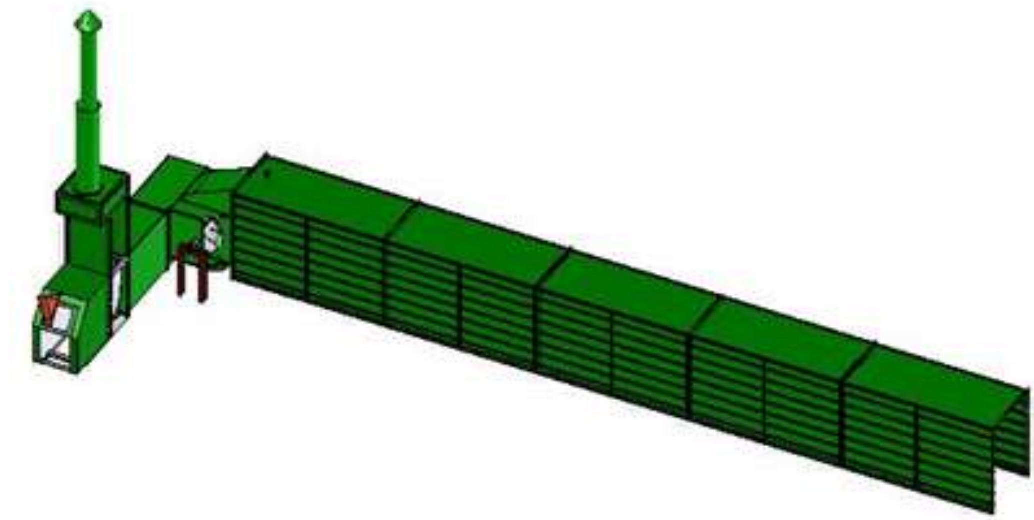


Fig.1a: The Tunnel drying Machine

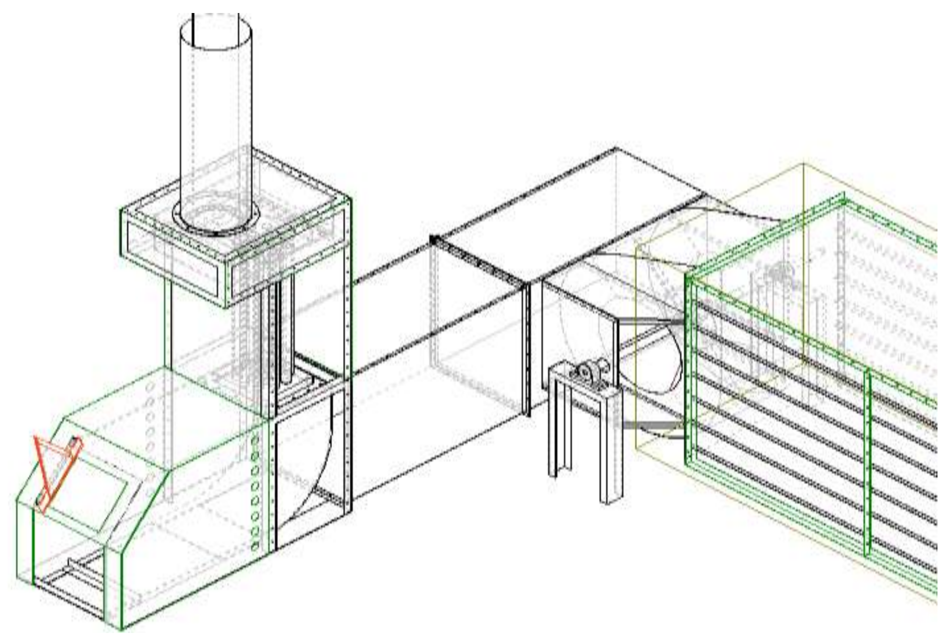


Fig. 1b: Wireframe of the working section of the tunnel dryer

THE DESIGN

The machine was designed with solid Works software.

Design Considerations

Some of the factors which were taken into account while designing the dryer included the following:

- Machine factors such as rigidity, durability, strength, vibration and stability were considered in the selection of appropriate materials for the various machine components to ensure reliability.
- The nature and characteristics of the material to be dried like temperature sensitivity were well considered in the design so as to deliver quality material after drying.
- Availability of material for cheaper and easy fabrication was also taken into account.
- The overall cost was considered through critical value analysis in the phases of design, material selection and production which at the end would make it affordable by intending users.

Design and Description of Machine Parts

The major designs were on the tunnel, hot air blower, heat exchanger and the pulleys.

The Tunnel

The tunnel is expected to hold 300kg of cassava chips at instant. It is a rectangular tube of 12m x 1m x1.2m was design to carry 98 pieces of 0.84m x 0.82m x 0.02m aluminium tray each that will contain a minimum of 3kg of cassava chips in a tray. The trays are arranged on the rails. Mild steel materials were used throughout being the most available and cost effective.

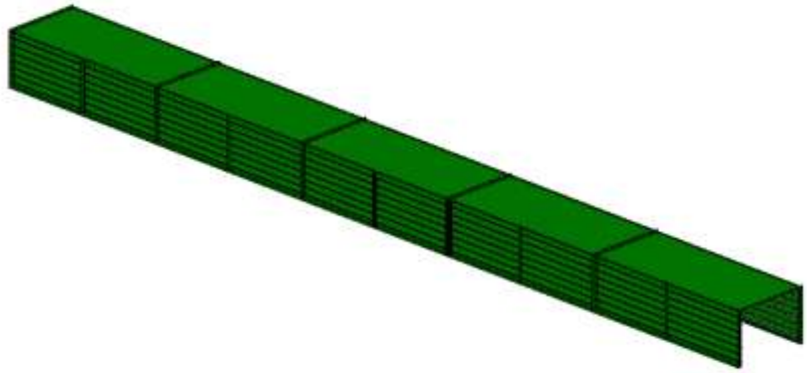


Fig.2a: 5 Coach Tunnel

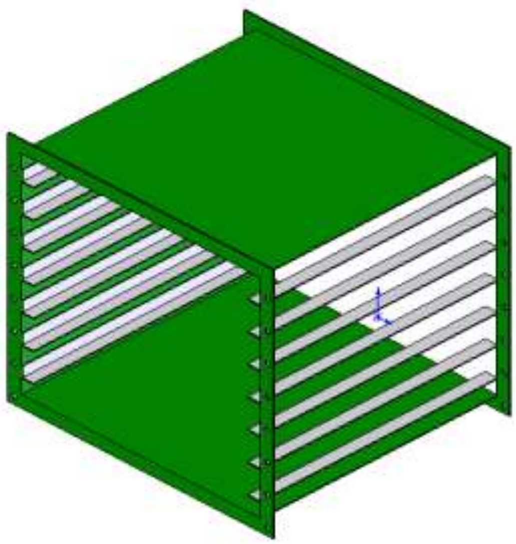


Fig.2b: A Coach showing the inner detail

Fig.2c: Drying tray (98 in number)

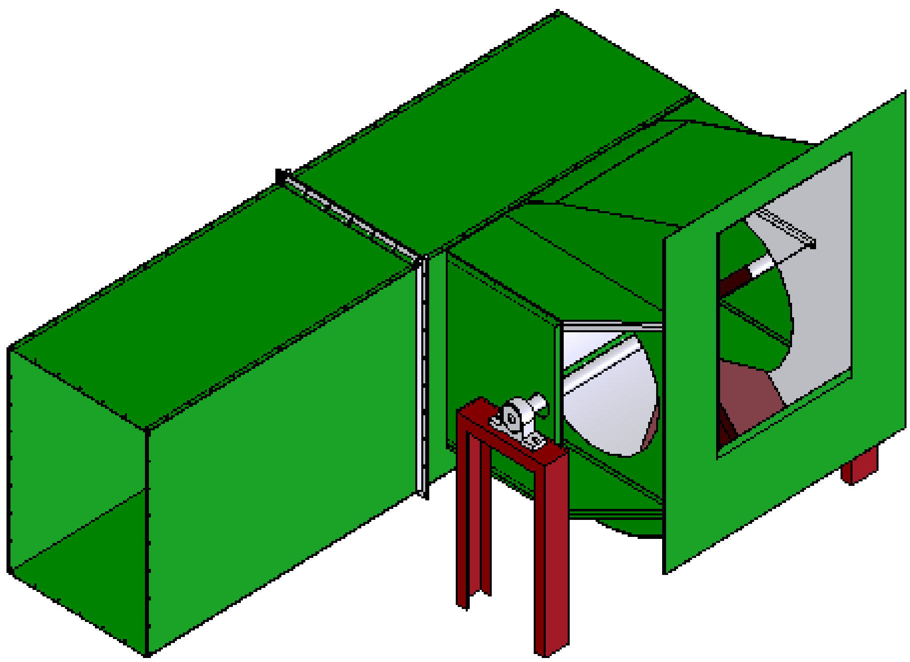


Fig. 3a: Hot air blower

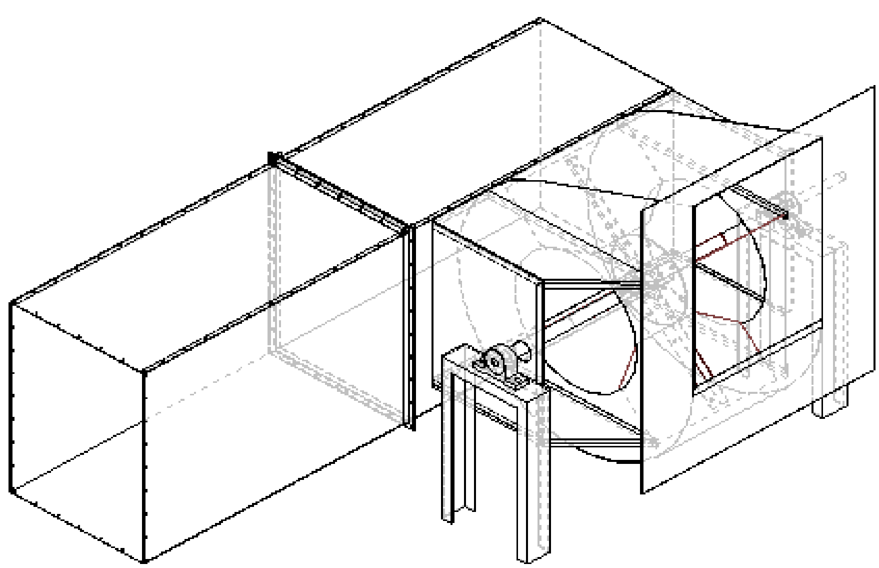


Fig. 3b: Wireframe of the hot air blower

The blower was meant to such hot air from the heat exchanger through the duct into the tunnel for the drying process. It has four fans on a shaft whose diameter was determined using the ASME Code equation for solid shaft having little or no axial loading (Hall et al, 1980).

$d3 = 16/\pi S_s \sqrt{\{(K_b M_b)^2 + (K_t M_t)^2\}}$ ……………………… (1)

Where d = shaft diameter (m), Mb = maximum bending moment (Nm), K_b = combined shock and fatigue factor applied to bending moment = 2 (for rotating shaft with suddenly applied load), K_t = combined shock and fatigue factor applied to torsional moment = 1.5 (for rotating shaft with suddenly applied load), Ssultimate stress of mild steel with keyway = 40MN/m2

Calculated shaft diameter = 38.5mm. From standard parts, 40mm diameter shaft was selected.

The blower is driven by 5hp variable speed gear electric motor via a v-belt on pulleys arranged. By using a variable speed motor pulleys of 1:2 was selected and the pitch length of the belt is given by John and Stephens (1984) as

$L = 2C + 1.57 (D2 + D1) + \{(D1 - D2)^2/4C\}$ ………………….. (2)

Where L = length of the belt (mm), C = centre distance between driving and driven pulleys (mm).The variable speed motor is use to regulate the air flow which is optimum at drying the cassava chips between 6m/s – 9.5m/s.

Heat furnace

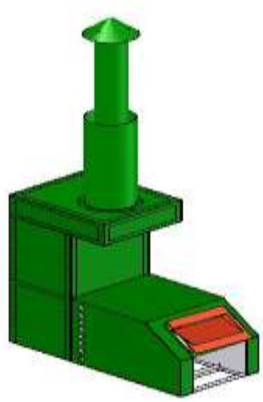


Fig. 4a: Heat furnace

The heat Furnace (exchanger) is made of mild steel material (6mm inner chamber and 2mm outer jacket with lagging material in-between). The heat generation is by wood or coal and the quantity of heat transfer Q, area A, and appropriate temperature difference is expressed as:
$Q = UA\ (T_I - T_o)$.

Where U is the overall heat transfer coefficient and A is the transfer area (assumed to be plane wall)

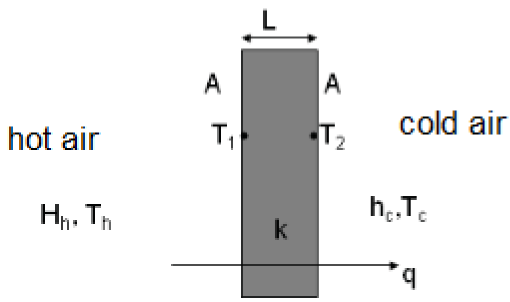


Fig. 4b: Heat model through a plane wall

$q=\frac{Q}{A} = h_h(T_h - T_1)$ Heat generated by fuel (wood or coal)

$q= \frac{k}{L}(T_1 - T_2)$ heat transferred through the wall

$q = h_c(T_2 - T_c)$ Heat transferred to the drying chamber

Rearranging and adding the above equations accordingly:

$$q = \frac{T_h - T_c}{\left[\frac{1}{h_h} + \frac{L}{k} + \frac{1}{h_c}\right]} = U(T_h - T_c)$$

Thus U is the overall heat transfer coefficient: $U = \frac{1}{\left[\frac{1}{h_h}+\frac{L}{k}+\frac{1}{h_c}\right]}$

FABRICATION

Marking out

The designed dimensions of the various components of the machine were marked out accordingly on the desired metal sheets.

Cutting out

The marked out components were cut accordingly with guillotine machine or hand angle cutter or hack saw depending on the size and nature of the component and material.

Welding

The components were welded as per design and ground to give a nice surface finishing. The welding is an electric arc welding and is varied according to the size and nature of the material being weld.

Assembling

The various parts of the machine welded are brought together accordingly and assembled with various sizes of bolts and nuts with accurate alignments.

Surface finishing

After the final assembling, the surfaces of the machine is treated with filler, primed and painted with the desired colour to give an aesthetic surface finishing.

DESIGN ANALYSIS

Appreciable quantity of cassava was chipped and fed and dried in the machine and calculation done based on the measured and available data.

DATA OF CASSAVA CHIPS

Initial Moisture Content, IMC = 65 % (wet weight basis)
Critical Moisture Content, CMC = 50 % (wet weight basis)
Size = 50 mm X 40 mm X 5 mm (approximately)
Thickness, x = 5 mm (approximately)
Density, ρ = 774 kg/m^3
Maximum allowable drying temperature = 60°C

Data of Tray

Length = 840 mm

Width = 820 mm
Height = 20 mm

Data of air

Relative Humidity, RH = 10%
Inlet Temperature, θ_a = 55°C
Air flow rate = 7 m/s (blown parallel)

Additional data

Final Moisture content, FMC = 15 % (wet weight basis)
Equilibrium Moisture Content, EMC = 9 % (wet weight basis)
Latent heat of evaporation of water, λ = 2300 KJ/kg
Surface heat transfer coefficient, $h_c = 14.3G^{0.8}$ (G is mass flow rate of air per unit area per second, $kgm^{-2}s^{-1}$) = $14.3\ (7)^{0.8}$ = 67.83 $Wm^{-2}K^{-1}$…. For parallel air flow
From Psychometric chart, wet bulb temperature, θ_s = 26.36°C, for Dry bulb temperature, θ_a= 55°C, at RH of 10% .

Assumptions

1. That drying takes place from the entire surface of the chips
2. That shrinkage does not occur.
3. Internal mass transfer is negligible.

Calculations

Quantity of heat produced by the fuel (wood or coal)

$H = mc\ (T_1 - T_0)$. Where

Heat flow through the surface of the heat exchanger

$Q = Ah_c\ (T_1 - T_2)$

Drying Rate

The rate of moisture transfer can be described well by the Lewis equation as follow

$$\frac{M_{t-M_e}}{M_{in-M_e}} = \exp(-kt)$$

$k = -\ln MR/t$

Drying rate (dry basis) can also be expressed as

$m_c = \frac{M_i - M_{ei}}{100*\Delta t}$ $(Kg_W/Kg_d.min)$

Drying time

$t = \frac{\rho\lambda x(M_c - M_e)}{h_c(\theta_a - \theta_s)} \ln \frac{(M_c - M_e)}{(M - M_e)}$

$m_e = 0.01 \left[\frac{\ln(1-f)}{-A(T+B)}\right]^{1/c}$

Efficiency

The heat efficiency ηduring drying period can be defined as ratio of heat Q_1 consumed by water of evaporation (at wet thermometer temperature) to the heat supplied by the heat furnace Q_2

$$\eta = \frac{Q_1}{Q_2}$$

CONCLUSION

A Tray-type semi-continuous Tunnel drying machine was designed, constructed and evaluated at Scientific Equipment development Institute, Enugu. The performance of the machine was quite appreciable with optimum performance at 170 rpm machine shaft speed which gives air flow rate of 8.5m/s. The entire construction was brought about by locally sourced materials thereby making the cost cheap and affordable. It is therefore recommended for small, medium and large scale processors. This will go a long way in adding value to cassava which is abundant in the country for foreign exchange and economic improvement of the country.

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LIST OF SYMBOLS

Where m_t = average moisture content at a time t, dry basis decimal
m_{in} = initial moisture content, dry-basis decimal
m_e= moisture equilibrium, dry-basis
t = drying time, min
L = length of tunnel
k = drying constant, min^{-1}
m = mass of wood or coal loaded in the heating chamber
c = specific heat capacity of wood or coal
T_2 = final temperature
T_1 = initial temperature
λ = Latent heat of evaporation of water
h_c = Surface heat transfer coefficient of heat exchanger,
v = volume per tray
ρ =Density of material in a tray
m_f =Final mass in a tray
N_t = Total numbers of tray
η efficiency