Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2020, 7(3):1-10

Research Article ISSN: 2394 - 658X

Manufacturing Considerations for the Design of Bi-thermal Multipurpose Convective Produce Dryer

E. E. Jumbo[1], E. Obaseki[2], S. R. Yelebe[3] and O. Obiga[1]

[1]Department of Mechanical Engineering, Niger Delta University, Bayelsa State, Nigeria
[2]Department of Mechanical Engineering, Federal Polytechnic, Nekede, Imo State, Nigeria
[3]Department of Mechanical/Mechatronics Engineering, Federal University Otuoke, BayelsaState, Nigeria
Corresponding author: dredjumbo@yahoo.com

ABSTRACT

The bi-thermal convective produce dryer proposed in this work is intended to be used for the drying of food and pharmaceutical products. The materials for which this machine could be deployed are not limited to any range of food produce or pharmaceutical material. The design is carefully conceptualized to incorporate varying degrees of considerations with respect to applicability in various situations. It considered the physical and chemical composition and characteristics of food and pharmaceutical products in the determination of the various parameters required for effective implementation and fabrication. Hence, of critical interest to the design is the heat loss prevention strategy where a high reflective material with good emissivity ε factor was used to coat the rock wool thermal insulation material in order to reinforce the stability of thermal balance required within the convective drying chamber. The essence of this internal thermal balance is to enhance the simultaneous drying of the loaded materials as to achieve even drying at the regulated time. Thus, the design is capable of gas fired application and electric heating filament drying. Interestingly, both methods can be used simultaneously and can also be deployed individually due to the efficiency of the twin temperature control which could be used to regulate the heating process.

Key words: upscale production, structural support, bi-thermal multipurpose, convective produce dryer, economic efficiency, hybrid design, refractive index, microwave energy

INTRODUCTION

It is noted that global trend in industrial development rely significantly on the manufacturing capabilities of nation states [1]. This drive for reliable national economic efficiency is sustained by production enabling activities, in terms of conceptualization and development of productive machineries and equipment [2]. Thus, manufacturing capability is crucial for the computation of global domestic productivityof any nation. Accordingly, this investigation and the subsequent design of bi-thermal multipurpose convective produce dryer, clearly indicate the need to upscale production processes for increased economic efficiency and development.

In view of the foregoing, this investigation is based on the need for the preservation of food and pharmaceutical products; and is intended to show that the deployment of the machine can increase the economic value of the processed materials. Consequently, the design took into cognizance the various proven scientific principles and applications that are incidental to heat transfer and mass flow, including related transport phenomenon involved in the gasification and extraction of moisture content of food and pharmaceutical raw materials. Hence, the investigation considered the deployment of external heating functionsthat energizes and excites the moisture and liquid content of the food materials to gaseous conditions, thus reconstituting or restructuring the internal composition of the food materials by the dissipated amount or quality of the food produce [3].

In view of the foregoing, the design of the multipurpose bi-thermal convective produce dryer for food and pharmaceuticals as proposed in this work shall be capable of dual heating strategy which deploy both electric element heating and gas fired heating. Thus, the design shall be composed of separate electric power heating source integrated into gas fired heating source on the basis infrastructural compatibility in terms of design and components integration.

Consequently, the hybrid design can be used alternatively depending on which suites the purpose and material to be processed. The implication of this design is that since different food materials require diverse heating strategies and priorities, the physical characteristics and structural composition of the food materials must be the basic consideration for any heating type to be used.

Relativity of thermal conditions and moisture content derivatives

The major compositions of most foods includes water, lipid, protein, carbohydrate, and enzymes. Each component has its own physical and chemical characteristics which contribute to the final properties of food products. Thus, the investigation for design parameters of this bi-thermal convective produce dryerfocused on the entire essence of food; in terms of its structure, additives, physicochemical properties, and functionality in structural changes resulting from post processing composition and properties of water, lipid, protein derivatives, carbohydrate, and enzyme. Since extraction of water or moisture content is the focus of this investigation, Table 1 below indicate the various properties and characteristics of water under rising temperature conditions ranging from 0°C to 100°C.Analysis of the composition of water under dynamic temperature conditions indicate that water properties are significantly affected by rising temperature. The implication of this for food processing is that heating process could be used to moderate the amount and quality of water properties available in food produce [3].

It has been suggested that since the moisture content of water in a food may not be accurately ascertained by mass of water in a known mass of food [3][4], the development to determine this thus rest on the ability to distinguish water (the analyte) from the other components of the food (the matrix). In order to achieve this, some characteristics have been analyzed, these includes, low boiling point, high polarity, ability to undergo chemical reactions with reagents, electromagnetic absorption spectra and physical properties such as density, compressibility, electrical conductivity and refractive index [3].

Thus, Table 1 is explanatory of the behavioral tendencies of the properties of the moisture content or water component of food materials under rising temperature conditions. It should be noted that a proper design of any convective produce dryer would significantly consider these attributes of water.

Table -1 Attributes of water

Properties and Parameters	Temperature (°C)					
Water	0	20	40	60	80	100
Vapor pressure(mmHg)	4.58	17.53	55.32	149.4	355.2	760.0
Density (g/cm^3)	0.9998	0.9982	0.9922	0.9832	0.9718	0.9583
Specific heat (cal/g °C)	1.0074	0.9988	0.9988	0.9994	1.0023	1.0070
Heat of vaporization (cal/g)	597.2	586.0	574.7	563.3	551.3	538.9
Thermal conductivity (kcal/m^{2}h°C)	0.486	0.515	0.540	0.561	0.576	0.585
Surface tension (dynes/cm)	75.62	72.75	55.32	69.55	66.17	62.60
Viscosity (centipoises)	1.792	1.002	0.653	0.466	0.355	0.282
Refractive index	1.3338	1.3330	1.3306	1.3272	1.3230	1.3180
Dielectric constant	88.0	80.4	73.3	66.7	60.8	55.3
Coefficient of thermal expansion x10^{-4}	-	2.07	3.87	5.38	6.57	-

Materials Selection and Methods for the Design

The material selection process for this design has to do withspecifications [5] in line with the nature of the produce to be dry-processed and the structural composition of the moisture to be extracted in the process. In this vein, the selection process for the structural support members considered materials that with significant strength and appropriate toughness, thus utilizing 50mm angle steel for fabrication of the structural support. Consequently, it has been opined that 'materials science predicts how to improve the properties of materials by understanding how to control their structures[6].This investigation thus considered the vital methods of materials property enhancement as the basis for selection; hence factors such as property enhancement through composition control (alloying), heat treatment, and controlling the structural processing of the material significantly informed the decision in the choice of the materials and components of the design. Secondly, since the dryer is intended to operate under high temperatures, the materials to be used must have undergone different measures of quality assessments and enhancements [7].

The following are the main components for this designand they are referred to as design keys and are numbered 1-19 as illustrated in Fig 1, Fig 2, Fig 4 and Fig 5; and in the analysis of the design in this work they are expressed as, DKNo.1- DKNo. 19.

1. Tray
2. Spring loaded swing door laced with appropriate insulation and reflector
3. Tray cover handle
4. Tray cover panel
5. Structural frame composed of 50mm angle iron
6. Main door handle

7. Slid roller with brake
8. Gas inlet valve
9. Gas distribution skid
10. Tray support base, indicating 85 inclination
11. Tray support made of steel
12. Moisture content draining vent
13. 25mm moisture drain link pipe
14. Moisture outlet nozzle with heat vent control
15. Terminal for electrical power connection
16. Heating element connector/link
17. Twin rectangular gas discharge burner
18. Needle hole gas discharge outlet
19. Electrical heat element elliptical ring

All the materials for the fabrication of this design can be sourced locally thus, making the design comparatively cost effective and economical to be fabricated. It should be noted that the materials were carefully selected during the conceptualization phase of the design and the applicability of the materials was assessed on the basis of their technical specifications to complement the design purpose [6].

Design Calculations and Parameters

The design calculations for the proposed bi-thermal multipurpose hybrid dryer took into account some theoretical and scientific principles and their accompanying state equations as detailed below:

Determination of humid heat of moist air

$$Cs = 1.0 + 1.87H \quad (1)$$

where;

Cs = humid heat of moist air, kJ/(kg·K);

1.0 = specific heat of dry air, kJ/(kg·K),

1.87 = specific heat of water vapor, kJ/(kg·K); and

H = absolute humidity, kg/kg of dry air.

The design requirement imposed on equation (1) deals with the permissible quantity of heat in moist air within and outside the chamber. In this regard, the air quality within the environment of the bi-thermal convective dryer must be determined to know the applicability of the design within the environment. Thus, the absolute humidity *H*, is determined by air quality of the environment.

Determination of adiabatic saturation, humidity and temperature:

In order to determine these parameters, the following relationship is articulated for computational analysis, thus:

$$Hs - H = (Cs / \lambda)\ (t - ts) \quad (2)$$

where

Hs and *ts* = adiabatic saturation humidity and temperature respectively, corresponding to the air conditions represented by *H* and *t,* and

Cs = humid heat for humidity *H.*

Cs /λ = The slope of the adiabatic saturation curve is,

λ = latent heat of evaporation at *ts*.

It is important to note that on the Psychrometric chart,equation (2) represent a family of lineswhich show the relationship between the temperature and humidity of air passing through a continuous dryer operating adiabatically. In practical terms, this investigation shows that the surrounding air on the material to be dried must be maintained at a pressure and temperature that must enhance the impact of the external heat source.

Determination of small to large mass evaporations ratios:

In the determination of the evaporation ratios of food produce, the wet bulb experiment was relied upon and it indicated that a dynamic equilibrium has to be established between heat and mass transfer, implying that the surface impact of heat was necessary for mass transfer in terms of evaporation. As in applications of microwave oven, 'the water molecules in the food evaporate because absorb microwave energy, which causes them to become thermally excited' [3]. This phenomenon is demonstrated in the evaporation of liquid from a small energy impact, like the food material in the proposed design to a large mass of energy, which does not affect the temperature or humidity of the large body of gas produced from the food during evaporation. This is expressed in the following equation (3):

$$hc(t - tw) = k'g\lambda(Hw - Ha) \quad (3)$$

where
hc = heat-transfer coefficient by convection, J/(m2·s·K) [Btu/(h·ft^2·°F)];
t = air temperature, K;
tw = wet-bulb temperature of air, K;
k′g = mass-transfer coefficient, kg/(s·m^2) (kg/kg) [lb/(h·ft^2)(lb/lb)];
λ = latent heat of evaporation at *tw*, J/kg (Btu/lb);
Hw = saturated humidity, at
tw = kg/kg of dry air; and
Ha = humidity of the surrounding air, kg/kg of dry air.

Design computation for gas heating function

Based on the findings leading to the design of this bi-thermal convective produce dryer; it should be stated that when the heat required for evaporation of the food materials in the constant-rate period is supplied by a hot gas, it indicates that a dynamic equilibrium has been established and the rate of heat transfer to the material and the rate of vapor removal from the surfaceof the material would be dependent on further supply of heat beyond this equilibrium [8]. This dynamic equilibrium is thus used to determine the size of the gas heating components that would be adequate for the mass of materials in the tray, inside the heating chamber. Thus, the gas heating function is expressed in equation (4) as follows:

$$dw/d\theta = htA\ \Delta t/\lambda = kgA\ \Delta p \qquad (4)$$

where;
$dw/d\theta$ = drying rate, kg water/s;
ht = total heat-transfer coefficient,J/(m^2·s·K) [Btu/(h·ft^2·°F)];
A = area for heat transfer and evaporation, m^2;
λ = latent heat of evaporation at *t ′s*, J/kg (Btu/lb);
kg = mass-transfer coefficient, kg/(s·m^2·atm) [(lb/(h·ft^2·atm)];
$\Delta t = t - t's$, where,
t = gas (dry-bulb) temperature, K;
$p = ps - p$,
where;
ps = vapor pressure of water at surface temperature *t′s*, atm; and
p = partial pressure of water vapor in the gas, atm.

In view of the foregoing, the design considered that the magnitude of the constant drying rate depends upon three factors:
1. the heat- or mass-transfer coefficient
2. the area exposed to the drying medium
3. the difference in temperature or humidity between the gas stream and the wet surface of the solid.

It should further be stated that these factors above, constitute the external variables. The internal mechanism of liquid flow does not affect the constant drying rate of the material.

Design Computation for Electrical Energy Heating Function

The proposed bi-thermal multipurpose convective dryer has an electric heating unit of the machine. This unit is incorporated into the design and located on the roof and floor of the dryer unit. Thus, it is designed to produce heat from the electric elements affixed to the top and bottom as shown in Fig 5 below.

In addition, heat from the electric element arrives at the evaporating surface from the roof walls by conduction through the wet material. For this case, in which both radiation and conduction are significant, the total heat-transfer coefficient is given by equation (5) as:

$$h_t = (h_c+h_r)\ [1+A_u/1+d(h_c+h_r)/k] \qquad (5)$$

where:
ht = total heat-transfer coefficient, J/(s·m^2·K);
Au = ratio of outside unwetted surface to evaporating surface area;
d = depth of material in tray, and
k = thermal conductivity of the wet material, J/[(s·m^2)(K/m)].

It should be noted that in this design, as indicated by equation (5), the two heat sources in the design can be made to operate at the same temperature and that the convection coefficients of the evaporating surface, with comparison to the unwetted portions of the tray are equal.

Determination of Wire Diameter of the Electric Element

In designing the requirement for the electric heating component, there is the need to calculate the wire diameter and length required to fit into the proposed design structure of the dryer as to enable it perform at the required maximum temperature of 120^{o}C, in such a case as in this design, the total resistance of the element at operating temperature (R_t) is expressed as:

$R_t = V^2 / W$ (6)

where:

V= Voltage (Volts)

W= Power (Watts)

R_t = Element Resistance at Operating Temperature (ohms)

Determination of Temperature Resistance Factor

In order to determine the temperature resistance factor within the range of 20°C and 120°C of thermal operation and on the basis of use of specific heating element alloy wire, the total resistance*(R)* of the element at will be:

$R = R_t / F$ (7)

where:

R_t = Element Resistance at Operating Temperature (ohms)

F = Temperature-Resistance Factor

Determination of Surface Area Loading

This surface area loading deals with the proportion of the heating element length and size with respect to likely area it can cover. This coverage should fall within the range shown in Table 1 below for heating element type. From the details on Table 1, it should be noted that a higher value of energy driveproduces a hotter element but with respect to this design, oven element in tubular sheathed shape has the capacity for producing between 8.0-12.0 W/cm^2.

This means that for every cm^2 area of the dryer chamber between 8.0 and 12.0 Watts of power can be delivered; implying that the value to be selected must match the drying range of the food feedstock. Thus, the surface area loading can be higher or lower depending on the amount of heat energy that would be required to effect the drying.

Table -2 Appliance, heating type and surface element range

Appliance	Element Type	Suggested Surface Loading Range (W/cm²)
Fire	Spiral Element in Free Air	4.5– 6.0
Fire	Pencil Bar	6.0 – 9.5
Band Heater	Mica-Wound Element	4.0 – 5.5
Toaster	Mica-Wound Element	3.0 – 4.0
Convector	Spiral Element	3.5 – 4.5
Storage Heater	Spiral Element	1.5 – 2.5
Fan Heater	Spiral Element	9.0 – 15.0
Oven Element	Tubular Sheathed Element	8.0 – 12.0
Grill Element		15.0 – 20.0
Hotplate		17.0 – 22.0
Water Immersion Heater		25.0 – 35.0
Kettle Element		35.0 – 50.0

(Source:www.heating-element-alloy.com/heating_element_factors.html visited: 2/09/2019)

In view of the foregoing, appropriate surface area loading (S) can be determined as follows:

$S = W/(l \times d \times 31.416)$ (8)

where:

S = Surface Area Loading (W/cm²)

W = Power (Watts)

l = Wire Length (m)

d = Wire diameter (mm

It should be noted that where practical situations of the fabrication and testing indicate that the calculated surface area loading is too high or low, then a redesign should consider a re-calculation of the following:

(i) the wire length and diameter

(ii) the grade of heating element alloy.

Determination of the loading area coverage of the heating element

A crucial aspect of the design is the determination of the lower and upper loading area coverage of the heating element. To determine this important feature, the total area was determined to be lx w (i.e.4ft x 2ft) i.e. 8ft^2.

or

1.23m x .6mm = 0.738m^2

Using the formula of arc length to determine the allowable curve of element to suite the shape of the rectangle:

Arc length= 2πr(θ/360) (9)

where θ is determined as 90^o being angle on a right angle and radius ***r*** is taken as 0.9ft.

Dynamics of Heat Transfer from Uninsulated Metal Plate

The study observed that the application of heat utilize the state equation expressed below:

$$q = U\Delta T \quad (10)$$

where;

q = local heat flux density $(W.m^{-2})$

U = overall heat transfer coefficient $(W.m^{-2}.K)$

ΔT= temperature difference

Accordingly, it should be noted that the overall heat transfer coefficient is dependent on the total thermal resistance of the material and its geometrical condition.In view of equation (10), consider the thermal balance due to heat transfer of a one-dimensional heat transfer system definitive of the bi-thermal convective produce dryer, the overall heat transfer coefficient in this regard, can be determined as follows:

$$U = \frac{1}{\frac{1}{h_1} + \frac{L_1}{k_1} + \frac{1}{h_2}} \quad (11)$$

where;

U= overall heat transfer coefficient $(W.m^2.K)$

K = material conductivity $(W.m^{-1}.K^{-1})$

h_1= convective heat transfer coefficient (inner wall)

h_2= convective heat transfer coefficient (outer wall)

L_1= thickness of the metal plate

Dynamics of Heat Transfer from Insulated Metal Plate

The overall heat transfer coefficient can be computed from equation (12) as follows:

$$U = \frac{1}{\frac{1}{h_1} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{1}{h_2}} \quad (12)$$

where;

U= overall heat transfer coefficient $(W.m^2.K)$

K = material conductivity $(W.m^{-1}.K^{-1})$

h_1= convective heat transfer coefficient (inner wall) $(W.m^{-2}.K)$

h_2= convective heat transfer coefficient (outer wall) $(W.m^{-2}.K)$

L_1= thickness of the metal plate

MATERIALS, METHODS AND DESIGN PROCESSES

The proposed bi-thermal convective dryer in this work is dependent on two fundamental and simultaneous thermodynamic processes, namely:

(1) heat is transferred to evaporate liquid, and

(2) mass is transferred as a liquid or vapor within the solid and exit the material as a vapor from the surface.

Thus, these factors control the mobility proportions of these processes and further determine the drying rate of the food and pharmaceutical materials.

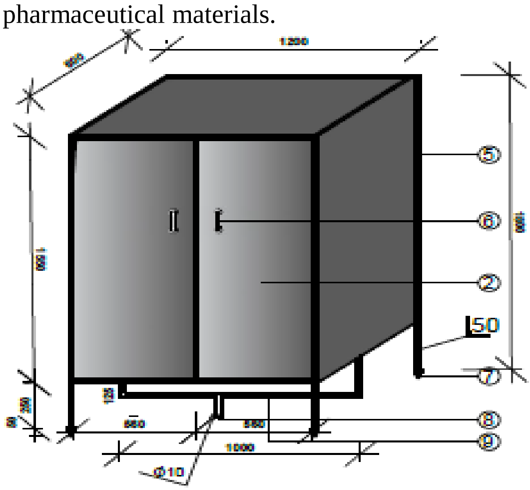

Fig. 1 Drying chamber with full external dimensions:1500mm x 1200mm x 600mm

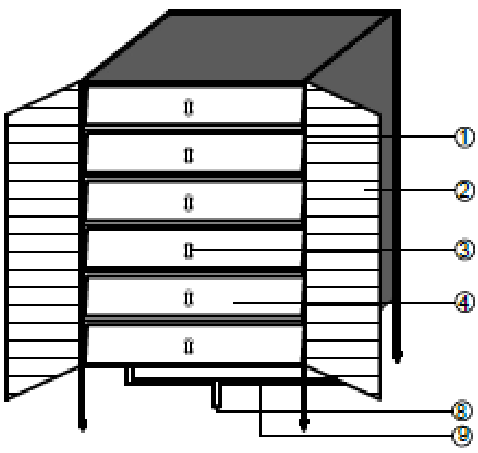

Fig 2. Drying chamber showing open doors and 85^o inclined tray complete with handle and panel

The materials and components for the design are selected on the basis of specifications and their mechanical properties and are labeledas shown in Fig 1, Fig 2, Fig 4 and Fig 5 are as follows: (1) tray (2) spring loaded swing door laced with appropriate insulation and reflector (3) tray cover handle (4) tray cover panel (5) structural frame composed of 50mm angle steel (6) main door handle (7) slide roller with brake (8) gas inlet valve (9) gas distribution skid (10) tray support base indicating 85^{o} inclination (11) tray support made of steel (12) moisture content draining vent (13) 25mm moisture drain link pipe (14) moisture outlet nozzle with heat vent control (15) electrical power connection terminal (16) heating element connector/ link (17) twin rectangular gas discharge burner (18) needle hole gas discharge outlet (19) elliptical ring of electrical heating element.

The two fundamental factors above are further dependent on transport rate operations which utilize heat transfer by convection, conduction, radiation, or a combination of these. This investigation found that in each of these cases of heat transfer, heat must flow to the outer surface and then into the interior of the solid to energize the liquid to find its way to the surface as to be vaporized and evaporated [8]. However, under dielectric and microwave drying processes, high-frequency electricity generates heat internally and produce a high temperature within the material and on its surface, thus making the group of dryers operate under different dynamic conditions.

Structurally, the method of this design favors situations where mass is transferred during the drying process as a liquid and vapor within the solid and as vapor from the exposed surfaces. Studies have indicated that such vapors also contain droplets of solid materials. Movement within the solid results from a concentration gradient which is dependent on the characteristics of the solid. Hence for a solid to be dried, it may be porous or nonporous, implying the necessity for osmotic pressure and surface tension conditions.

The design process indicate that the heating element would be located at the floor of the chamber and also at the roof of the chamber. This arrangement is intended to ensure a faster transfer of heat from bottom and top while the removal of solvent vapor produced in the course of the drying process is conveyed from the little opening and at the rear of the inclined tray. This vent conveys the vaporized liquid through the back of the drying machine. A vent was also provided at the top right hand corner of the dryer to allow for a better air movement within the compartment; it was also anticipated that the drying temperature should not be in excess of 80^{o}C. Thus, the top vent is designed to act as an ambient temperature control mechanism which operate by the extraction of heat after temperature impact on the food material.

At this temperature, a ten percent (10%) relative humidity would be achieved for drying food items such as yam, maize, potatoes, etc. However, owing to the maximum temperature of 120^{o}C provided for under Psychrometric chart, temperature could be regulated as not to exceed this range of 20^{o}C to 120^{o}C in order to accommodate a wide variety of food materials including meat and fish that has significant moisture content.

Further, the effect of food poisoning resulting from unhygienic drying processes was considered and analyzed in the course of selecting the materials used for the design of the multipurpose hybrid dryer. Further, the fabrication of this proposed bi-thermal convectiveproduce dryer would diffuse any of the poisonous elements in any food material, or that may be present as a metallurgical consequence of inappropriate material selection. Consequently, the design in line with standard procedure for diverse materials integration of this nature [9] took all materials selection parameters such as strength analysis, failure analysis, structural reconfigurations, reliability and availability analysis, etc into processing considerations [10].

FINDINGS AND DISCUSSIONS

Structural Dynamics of the Design

The proposed design is structurally balanced on the basis of proper calculations of the supporting members and trusses, on the basis of the structural integrity of the welded joints [11]. The physical structure is composed of steel materials made up of 6ft x 4ft x 2ft based on 2''x 2''angle steel. The stability of this reinforced and properly braced support structure is further maintained by the inclusion of a rollerfooting incorporated with dynamic brakes and stopper as shown in Fig 1 and 2 above.

Analysis of Gas Fired Component of the Design

The gas heating component of the convective produce dryer is in cognizance of the high temperature output capability of natural gas and the safety measures that are required under such application. Thus, we shall analyze the gas fired component of the design as demonstrated below.

As could be seen in Figs 1 & 2 above, the external dimensions of 1500mm x 1200mm x 600mm are the support structure made of 2''x2'' angle steel as indicated by L50. There are internal reinforcements made of cross welded bracing and trusses to create high stability and balance, as to withstand the varying load sizes of the food feedstock.

Thus, Fig 2 indicates the front view of the convective dryer when the doors are open and the tray drawers are closed. It should be noted that the door, top bottom and sides of the dryer are laced with the appropriate heat insulation material to control heat losses due to convection and radiation. Further, a careful observation would indicate that the tray drawers labeled as Design Key No 1 (DKNo. 1) are slightly slanted indicating 5^{o} inclination angle from the rear of the tray. This inclination angle drives the liquid mass from the entire surface of the closed tray to the liquid heat vent located at the back of the machine as shown at DKNo. 14-moisture outlet nozzle with heat vent control identified as DKNos. 10 and 14 of Fig 4 below.

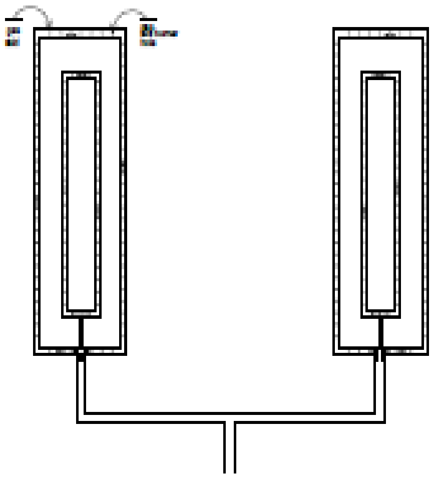

Fig. 3 Outlay of the gas heating system of the proposed design

Further, DKNo 2 indicates spring loaded swing door. This special door ensures there is no unauthorized escape of heat from the dryer chamber as it returns the door upon release due to the spring returning coupling. Further note that DKNo 4 is the tray cover panel that also ensures that the feedstock is well protected and heat is preserved inside the chamber. It creates opportunity for air to be properly circulated from the controlled air inlet hole positioned at the back of the machine.

Further, DKNo 9 and DKNo 10 of Fig. 8 and Fig 9 are the inlet valve and gas distribution skid,with illustration at Fig. 3 above and Fig 5 below. These items are designed to convey and regulate the flow of natural gas from external cylinders into the twin rectangular gas discharge burner (DKNo 17). This single input gas inlet system depicted in Fig 3 and Fig 5 is designed to distribute the gas on the basis of a special inlet valve control which also serve to regulate temperature of the heating process by either increasing or reducing the volume of inlet gas and using this means to control the amount of input gas.

In addition to the foregoing, the design is intended to discharge the food material moisture or liquid through DKNo. 12 which is the moisture content drain vent, which is a running pipe connected at each tray level through 25mm moisture drain link pipe (DKNo 13). This pipe, causes a flow from the rear of the tray into the drain link pipe and is discharged at DKNo 14.

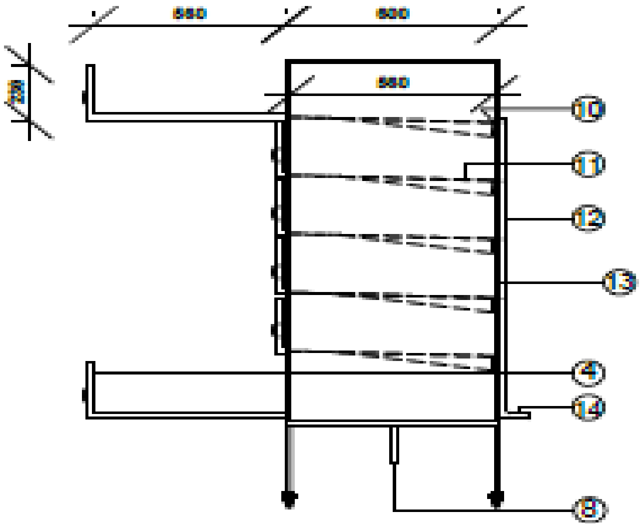

Fig. 4 Sectional view of the design showing internal structure of component arrangement

Further, a careful observation of Fig 4 shows the support base of the tray inclined at about 5^{o} degrees. The essence of this type of support is to create easy mobility of fluid and to also control the waste discharge.

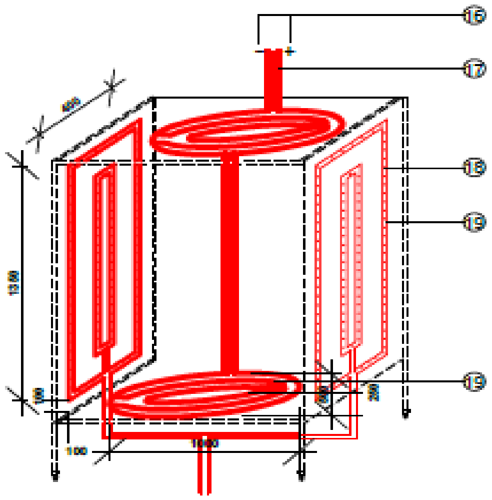

Fig. 5 Structural design of dual gas and electrical heating systems

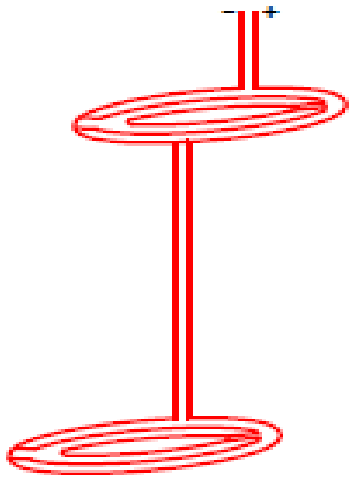

Fig. 6 Electrical Tubular Sheathed Element

Analysis of the Electrical Heating Component

The electric element powered aspect of the design deals with the analysis of parameters expressed in the equations above. These calculations include, determination of surface area loading, determination of temperature resistance factor, determination of wire diameter of the electric element and determination of heating function, etc. These parameters formed the basis for the design and can guide the fabrication and testing process.

In Fig 5 and 6 the structural design of the electrical components of the design could be seen. The electrical tubular element whose parameters were defined and determination formulas were also stated, should be seen to be a fold-in design which has the capability to impact heat at 100% of its calculated power output of 8.0 – 12.0 W/cm2 with the appropriate heat insulation measure described above. As could be seen, the input is a positive and negative terminal which has the ability to receive and transmit current.

By design the input current is made to pass through a high resistance wire as supported by equation (9) and (10). These expressions indicate that the efficiency of the heating system is directly proportional to the extent of resistivity of the wire through which the heat is impacted on the materials.

Thus, the design indicates that heating effect from the bottom and top of the chamber for the electrical heating unit is a very efficient design contemplation. This energy efficient design of the electrical component took cognizance of the size of the floor or base and roof of the chamber by using the equation for determination of arc length to assess the coverage of the heating element loading area.

As seen in equation (9) above, the length of the arc was determined by taking radius *r* of the arc to and the subtended angle 90^{o} due to half length of a diameter. Thus, the foregoing computation enabled the designers to calculate the total length of the tubular element component that would be reshaped to suit the intended coverage area as discussed above. Further, it should be noted that the electrical heating component has the ability to impact heat in the form of heat waves on the food materials as it operates like an electrical oven. This means that input voltage which determines the extent of current, should be dependent on appropriate resistivity. The output of this process produces temperature which could be controlled by the amount of voltage input.

Surface Reflexivity and Insulation of Inner Wall

The investigation revealed that in order to decrease the amount of heat loss from the convective drying chamber due to conduction and convection, a material with low emissivity (high reflectivity) should be used as a coating material for the rock wool insulator component. It should be noted that reflective insulations are usually composed of multilayered, parallel foils of high reflectivity, which could be arranged or spaced to reflect thermal radiation back to its source, thereby maintaining the required range of temperature without heat losses. In such a cases, the characteristic emissivity,$\varepsilon$of the surface of the reflective material determines the effectiveness in emitting radiated heat energy back to the chamber. In this regard, thermal radiation for materials within the range of application of this study varies between 0.0 and 1.0;consequently, the study observed that polished metals have very low energy emissivity and are appropriate for use in the proposed design, however, the cost of such metals defeat the economics of design and therefore may not serve the economic value expected of such designs. It is therefore important to note that material selection process is very crucial in the determination of appropriate insulation for the machine; as economically and technically viable alternatives should be considered when components for the bi-thermal produce dryer are being integrated.

REFERENCES

[1]. L. N. Chete, J. O. Adeoti, F. M. Adeyinkaand O. Ogundele, (2016) Industrial Development and Growth in Nigeria: Lessons and Challenges, the study is a collaborative activity under Learning to Compete (L2C) initiative of the Africa Growth Initiative at Brookings (AGI), the African Development Bank, (AfDB), and the United Nations University World Institute for Development Economics Research (UNU-WIDER) on industrial development in Africa. Available at: www.brookings.edu/wp-content/uploads/2016/07/L2C_WP8_Chete-et-al-1.pdf visited 4th January, 2020.

[2]. J. DiSano, (2007) Industrial Development for the 21st Century: Sustainable Development Perspective Department of Economic and Social Affairs, United Nations. New York, p.30-33 Available at: www.sustainable development.un.org/ content/documents/full_report.pdf visited 4th January, 2020

[3]. J.M. deMan,J.Finley, W.J. Hurst,C.Lee, Principles of Food Chemistry 4th Edition, Springer International Publishing AG, Switzerland, 2018, p.123-124

[4]. W. A.Horwitz, M. J. Deutsch, and J. N.Thompson, Precision parameters of methods of analysis required for nutrition, Labeling. Part I. Major Nutrients. J. AOAC 1990, 73:661-680.

[5]. W. D.Callister Jr, Materials Science and Engineering, An Introduction, 6th ed, John Wiley, NJ, 2003, p. 144

[6]. D. E.Dieter and L.Schmidt, Engineering Design, Mc Graw-Hill, New York, 2009, p.461

[7]. European Science Foundation, Materials Science and Engineering in Europe: Challenges and Opportunities, Science Position Paper. Available online at:www.archives.esf.org/fileadmin/Public_documents/Publications /MatSEEC_ChallengesOpportunities.pdf 2013, p.8 visited 5th Jan., 2020

[8]. Z.Berk, Food Process Engineering and Technology, Elsevier, Oxford, 2009, p.430-431

[9]. R. M.Jones,Mechanics of Composite Materials, 2nd Edition, Taylor and Francis Publishers, Philadelphia, 1999, p.381-383

[10]. E. E.Jumbo,Advancements in Mechanical Engineering Practice and Optimization of Sustainable Economic Development: A Comparative Analysis, International Journal of Innovative Research and Advanced Studies (IJIRAS) Volume 5 Issue 5, May 2018

[11]. E. E.Jumbo, Chemostructural Conditionalities for Welderbility in Nickel-Chromium Sequenced Dual Nucleation: American Journal of Engineering Research (AJER) Vol. 3, Issue 4, April 2014.