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Tesis

Design of a Forced Internal Convection Dehydrator to Improve the Productivity of Ginger (Zingiber officinnale) in Pichanaqui, Junín-Perú in 2021

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Design of a Forced Internal Convection Dehydrator to Improve the Productivity of Ginger (Zingiber Officinnale) in Pichanaqui, Junín-Perú in 2021

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***Abstract*—This research work develops a forced internal convection dehydrator to improve the productivity regarding ginger dehydration in Pichanaqui and the objective is to design an internal forced convection dehydrator using a centrifugal fan to maximize the productivity and to improve the quality of the dried ginger. This research is based on the German design norm VDI 2221 which was adapted and complemented with the norm VDI 2225. Furthermore, it was added the state of the art and also 7 phases for the development of the objective. Those points were implemented in order to determine the list of requirements and desires, the abstraction process or black box, the sequence of operations, a solution analysis or white box, a morphology matrix, a technical economic analysis to finally obtain a preliminary project. The results of the mathematical modeling determined that for the feeding system there is a hopper and a worm screw that doses and transfers the fuel with a flow of 4.5 [kg/hour] to keep the heat generated inside the combustion system, which is made of 310 refractory stainless steel and vermiculite plate as thermal insulator, with internal tubes that function as filters and heat exchangers for the circulation system connected to a rectangular duct that joins both rooms circulating at 9. 012 kg/min of air forced by a fan of 4750 m^3/h and with a dehydration temperature of 59.89°C, production capacity of 274.47kh/day, made of 304 stainless steel and glass wool insulation.**

***Index Terms*—ginger, dehydrator, forced internal convection, heat transfer, productivity, design**

I. INTRODUCTION

Ginger is considered as the most widespread natural remedy worldwide, and this is due to its outstanding medicinal properties [1]. Because of this, the interest of international markets for its export has increased, mainly in the USA [2] by 110% in terms of volume and 97% in value [3]. Consequently, it is presented as a great alternative for 3000 producers and 84 agro-exporting companies in Pichanaqui to transcend the Peruvian presence into a competitive international market. The current traditional and rudimentary post-harvest process is based on direct sun drying, which shows poor product quality due to exposure to organic residues and contamination due to the environment ginger is kept [4] as shown in figure 1. There are many food preservation techniques, being freezing the most common as well as boiling the food at high temperatures which destroys microorganisms being the appropriate temperature between 60° to 90 °C to ensure the destruction of microorganisms and avoid product degradation [5] Other methods include restricting the oxygen by means of containers and eliminating the humidity[6]. With respect to ginger, the main factor to maintain its quality is the temperature at which it is dehydrated being the optimal between 52 to 60 °C [7]. As this influences the uniform extraction of humidity, it should not be greater than 10% [8]. Therefore the traditional dehydration demands a greater time for the exportation.

So in recent years many designers opted for the moisture removal technique and research is being conducted in different parts of the world and by doing so they provide a lot of information regarding the development of different designs so as to improve the current knowledge on how to obtain a better quality product, as in this research case, for exportation. For the different designs made, there is one which was developed in Mexico (2017) [4]. The author designed, constructed and evaluated a solar dryer employing theories in thermodynamics, thermal analysis for the design of said machine. As a result, it was dehydrated 100 kg of mango in an area of 15.12 m^2 (drying chamber) where 12 trays were distributed evenly inside which held 8.33 Kg/tray decreasing the humidity from 80% to 8.4% in 8 hours. In the article published and

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titled "Design and Simulation of a Mixed Indirect Fruit Dehydrator" made in Chimborazo, Ecuador in 2020, it was developed an indirect type dehydrator, where the heat transfer occurs by forced internal convection. Obtaining as the most remarkable conclusion an air flow of 1.68 m^3 for a capacity of 50 Kg and with a temperature varying from 40 to 70 °C in order not to lose the product characteristics in a lapse of 7.3 hours [9]. Regarding the type of drying applications and energy used, this research [10] considered an energy evaluation that focused on energy quality, not quantity, and also focused on two food drying applications: heat pump assisted drying (SBC) and convective drying with total recirculation (SCC). The average initial moisture content of fresh carrot was 0.8935 (bh) or 8.39 (bs). From 17 experiments for a fixed time of 5 h. It was found that convective drying with total recirculation (SCC) is possible with outstanding performance. On the other hand, artificial drying refers to the application of organic fuel, or from gas or electricity and the research article [11] named "Utilization of rice husk biomass in conventional corn dryer depending on the diameter of heat exchanger pipes" Mataram - Indonesia (2020) was based on the theories of heat transfer by forced convection and thermodynamics by applying it in the heat exchanger for the conversion of rice husk into thermal energy by prototyping a furnace with steel plates and stainless steel tube for hot air circulation with a temperature of 72, 79 °C and 109.20 °C with a forced convection system using an exhaust fan. Regarding the proposed design in this project, the ginger dehydrator, it comprises of a feeding system that has a deposit hopper for receiving the biomass (coffee husk which acts as fuel) and a worm screw that doses and transfers it with a flow rate of 4. 5 Kg/hour [12] to keep the heat generated inside the combustion room which is made of 310 refractory stainless steel and vermiculite plate as thermal insulator, with some internal tubes that work as filters and heat exchangers for the circulation system. It is connected to a rectangular duct that joins both rooms where the air flow (9. 012 kg/min) is forced by a fan of 4750 m^3/h and with a temperature for dehydration of 59.89°C. The capacity of the dehydration chamber is 274.47 kg/day which is contained in 38 trays and distributed in 2 columns. The internal wall is made of 304 stainless steel and glass wool insulation as external wall. For this reason, the design of the ginger dehydrating machine is made to offer ginger an added value to improve its quality and increase the productivity so as to compete in the national and international market.

Figure 1. Traditional and rudimentary dehydration of ginger in the city of Pichanaqui.

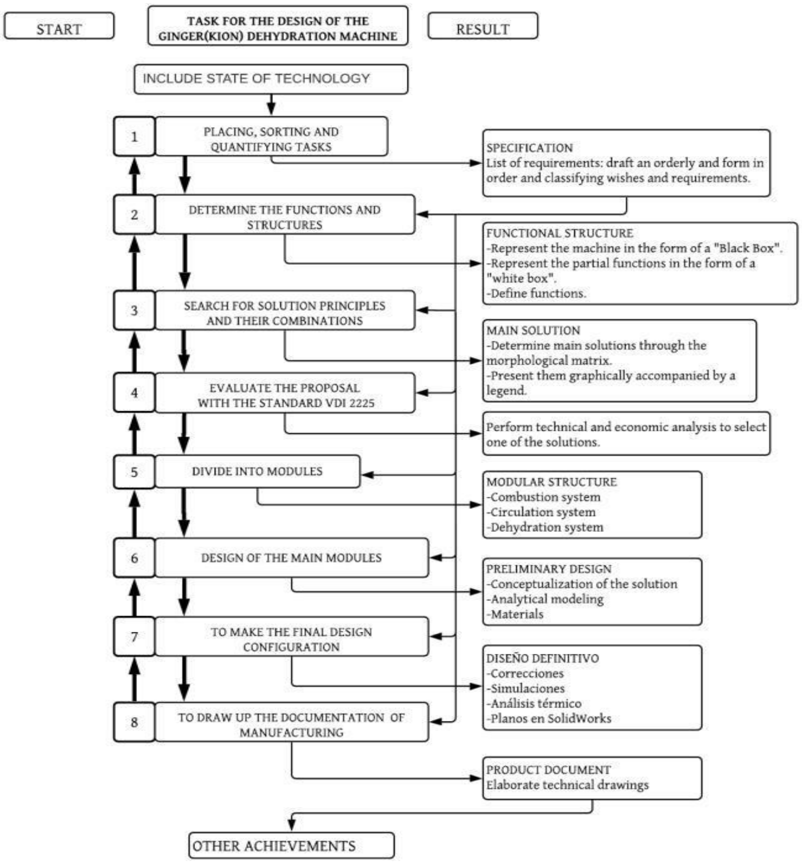

Figure 2. Diagram of the design stages and processes adapting the design structure according to VDI 2221 complemented with VDI 2225 that develops the technical and economic analysis for the design of a forced internal convection dehydrator to improve ginger production.

The purpose of this research project was to design a ginger dehydrator machine by forced internal convection which had to be simulated to measure the fulfillment of the set objectives. For this research, it was used a non-experimental quantitative approach of technological type and the applied methodology to carry out the Project was adapted from the VDI 2221 norm and complemented with the VDI 2225 norm (Fig. 2). Those mixed methodologies were used to include the technical-economic analysis. Apart from what it has been mentioned previously, the sequence of operations (Fig. 3 was detailed and the order of the processes was established. As a final, but important part, knowledge in heat transfer, turbomachinery and fluid mechanics was applied to the development of the project which helped greatly to avoid mistakes regarding the different systems which had to be designed and calculated [13].

The materials used in the current research were selected according to the systems of the machine. Those were classified in Table I.

II. MATERIALS AND METHODS

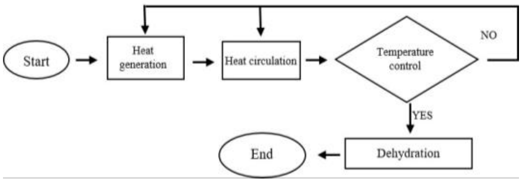

Figure 3. Sequence of operations

TABLE I. MATERIALS SELECTION ACCORDING TO THE SYSTEM

Item	Material
Feeding system	AISI 304 stainless steel
Combustion system	AISI 310 refractory stainless steel and vermiculite
Dehydration system	AISI 304 stainless steel and glass wool
Circulation system	Galvanized steel and AISI 304 stainless steel

III. RESULTS AND DISCUSSION

A. *Feeding System*

The feeding system consists of a deposit hopper and a worm screw. Its function is to dose the coffee husk (biomass) in order to have enough fuel to keep the required heat for the machine to operate within the established parameters. The results of the calculations together with its parameters are shown in Table II.

TABLE II. EQUATIONS USED AND RESULTS

Parameters	Equation	Results
Conical hopper volume	$V = \left[\frac{h}{3}(a^2 + b^2) + ab\right] + a^2c + b^2d$	$V = 0.16\, m^3$
Hopper capacity	$C = v * d * H * (fv)$	Capacity =31 Kg
Transport capacity	$S = \lambda \frac{\pi D^2}{4}$	$S = 0.00314\, m^2$
Conveyor travel speed	$V = \frac{p * n}{60}$	$V = 0.3\, \frac{m}{s}$
Coffee husk flow	$Q = 3600 * S * v * p * i$	$Q = 0.00125\, \frac{Kg}{s}$
Drive power	$P = P_H + P_N + P_I$	$P = 0.59[Hp]$
Coffee husk falling speed	$V_s = \frac{2}{9} \frac{r^2 g(p_{husk} - p_{air})}{n}$	$Vs = 0.20\, \frac{m}{s}$
Endless feeder output area	$\dot{m} = p(V.A)$	A = 0.011 m^2

B. *Combustion System*

The combustion system comprises of the chamber where heat is generated by means of combustion, i.e. the transformation of potential chemical energy into thermal energy. In this place the fuel is burned, in this case the coffee husk, which is in contact with a certain amount of air, also known as the air-fuel ratio. It was performed the thermal analysis by the walls in Fig. 4, resulting in an external temperature of 40.5 [°C]. Table 3 shows the equations used along with its results

TABLE III. EQUATIONS USED IN THE COMBUSTION SYSTEM

Parameters	Equation	Results
Total heat quantity in the combustion chamber	$Q = C_p * m * (T_f - T_a)$	$Q = 6935.80\ kJ$
Amount of air per kilogram of mass	$V_{air} = \frac{1}{Air\ density\ at\ max.temp}$	$V_{air} = 0.8579\ \frac{m^3}{kg}$
Specific mass of air	$P_a = \frac{1+W}{V_{aire}}$	$P_a = 1.16\ \frac{kg}{m^3}$
Required air mass	$M_{a.r.} = \left(\frac{1.37931}{P_a}\right) * \left(\frac{Xc}{12}\right) + \left(\frac{Xh}{4}\right) + \left(\frac{Xs}{32}\right) - (\frac{XO2}{32}))$	$M_{a.r.} = 2.96\ \frac{m^3}{Kg}$
	C. de aire=$M_{air\ reuired} * M_{biomass}$	C. de aire =13.32 $\frac{m^3}{h}$
Power to heat the air	N=$\frac{\rho_a * C_p * \Delta T}{\eta}$	N=25304.045 $\frac{KJ}{h}$
Total volumetric capacity of dehydrator	V=$\frac{N}{Le}$	V=0.13 m^3
Chamber material selection	Inner material: Refractory stainless steel 310, thickness 0.002[m]	
	Insulating material: vermiculite plate, thickness 0.075[m]	
Thermal resistors	$R_T = \frac{l}{K}$	$AR_T = 0.0001143\ \frac{m^2}{w}$
		AR_T =1.0714 $\frac{m^2 * C}{w}$
Heat flux per unit area	$\dot{q} = \frac{T1 - T\infty e}{AR_{Tinsul+}AR_{Tinox+}AR_{T\infty e}}$	762.92 $\frac{w}{m^2}$
Heat Transfer Ratio	$\dot{Q} = \frac{T_1 - T_{\infty e}}{R_{inox} + R_{insul} + R_{\infty e}}$	$\dot{Q} = 336.45$ W
Temperature outside the room	$\dot{Q} = \frac{T_3 - T_{\infty e}}{0.04}$	T_3 =40.458 °C

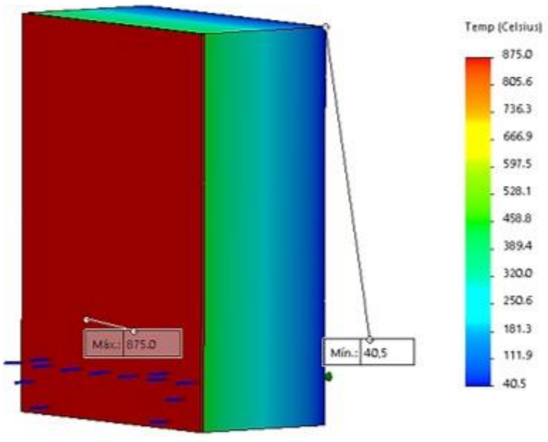

Figure 4. Combustion room wall temperature simulation performed in thermal simulation by SolidWorks 2019 software.

C. Circulation System

The circulation system comprises of heat transfer by internal forced convection by means of a centrifugal fan with backward blades which had 90% efficiency taking the dehydration at high temperatures with a flow rate of 1.3 m/s for combustion [14]. From the table below (Table IV we can see the parameters taken into account.

TABLE IV. CIRCULATION SYSTEM CALCULATIONS

Parameters	Equation	Results
Duct hydraulic diameter	$dH = \frac{4AC}{P}$	$dH = 0.4333\ m$
Fluid temperature	$\mathrm{Tf} = \frac{\mathrm{T_e + Ti}}{2}$	63.43 °C
Mass flow	$\dot{m} = \rho * v *$Ac	$\dot{m} = 0.1502\ \frac{kg}{s}$
Surface area	As=$\pi * D * l$	As=0.0478 m^2
Convection coefficient	$R_e = \frac{\rho * v * D_h}{\mu}$	R_e=67293.72
Nusselt number Calculation	Nu=0.023$Re^{0.8} * Pr^{0.4}$	$N_u = 146.849\ \frac{W}{m^2 * C}$
Convection coefficient	$h = \frac{N_u * k}{D_H}$	$h = 9.5977[\frac{w^2}{m^2 * c}]$
Oulet temperature calculation	$\frac{T_s - T_e}{T_s - T_i} = e^{-\frac{h * As}{\dot{m} * Cp}}$	$T_e = 59.89\ °C$
Internal heat flow in the duct	$\dot{Q} = m * Cp * (Te - Ti)$	$Q = -6045.51\ W$
Centrifugal fan selection is according to the flow rate.	The centrifugal fan chosen according to the flow rate recommended by FAO for the dehydration process at high temperatures is 4750 m^3/h of flow rate model CSXRT of 0.55Kw commercial power of the Sodeca brand.	

Every second 0.1502 kg of air will move through the duct, being 9.012 kg with an outlet temperature (Te) of 59.89 °C.

D. *Dehydration System*

The dehydration system is where all the heat will be concentrated as well as the feeding of the ginger carried on tray holders and positioning those perforated trays inside the chamber. Thus, it allowed the thermal analysis on the walls, figure 5, obtaining a temperature of 28.17°C on the external part. The data used are shown in table 5.

TABLE V. Calculation of Parameters for the Dehydration System

Dehydration System		
The ginger dehydrating machine must dehydrate $\frac{274.47Kg}{day}$ of fresh ginger.		
Dehydration room dimensions	Length 1500 [mm], Width 900 [mm], Height 1810 [mm]	
Trays dimensions	Width 800 [mm], Length 600 [mm], Height 40[mm]	
Dehydration chamber volume	$V = width * lenght * height$	V_{total}=2.4435$[m^3]$
Ginger volumetric capacity	$V = width * lenght * height$	V_{ginger}=2.1692$[m^3]$
Room material selection	Inner material: Stainless steel AISI 304, thickness 0.002[m]	
	Insulating material: Glass wool, thickness 0.04 [m]	

The dehydration system has a capacity of 274.47 Kg/day and was designed according to the dehydration temperature and the production of ginger in Pichanaki.

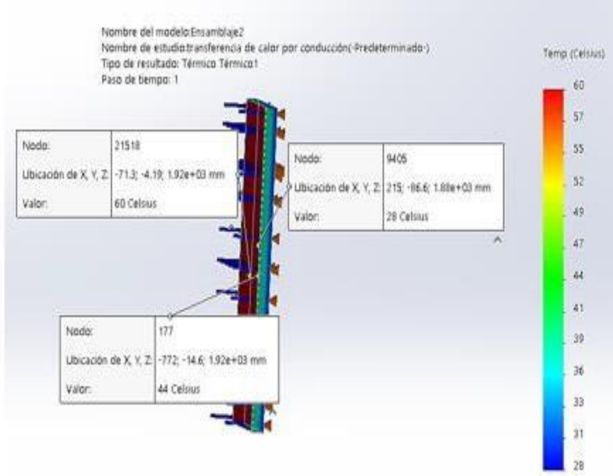

Figure 5. Simulation of the temperature difference by walls elaborated in thermal analysis in SolidWorks 2019.

IV. Conclusions

The forced internal convection dehydration machine was designed to improve the productivity of ginger in Pichanaqui with respect to the producer's requirements.

By applying the methodology described earlier, it was determined that the feeding system has a hopper and a worm screw that doses and transfers the fuel with a flow of 4.5 Kg/hour to keep the heat generated inside the combustion system, which is made of 310 refractory stainless steel and vermiculite plate as thermal insulator, with internal tubes that function as filters and heat exchangers for the circulation system connected to a rectangular duct that joins both rooms circulating 9. 012 kg/min of air forced by a fan of 4750 m^3/h and with a dehydration temperature of 59.89 °C, the dehydration capacity is 274.47 kg/day, made of 304 stainless steel and glass wool insulation.

Conflict of Interest

The authors declare there were no conflict of interest.

Author Contributions

Authors contributed to the planning, calculations, design, simulation and the writing of the manuscript.

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