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Food Dryer Design and Analysis of Velocity and Temperature Profiles

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Abstrac

The chamber of a hot air dryer is the most important zone within the process of moisture extraction focused in food. Because of this, it is necessarily make a control of its variables for guarantee the homogeneity in velocity and temperature. For this, is possible identify how are the contours within a simulate environment using CFD methods and with this, modify the necessary for improve the performance of the system. According with that, in this work was made a design of a hot-air dehydration system focused in food, proposing different configuration of the trays and position of the inlets an outlets of air flux. With these designs were made the analysis of the contours of temperature and velocity from the CFD simulations made in the tool Flow simulation of the Solidworks software. With this, it was found that the geometry that guarantee uniformity in the average value of the velocity and temperature in the chamber, is a system with outlets in both sides and horizontal trays.

Keywords: Dehydration, CFD , simulation, food , exchanger.

INTRODUCTION

Now days, it is possible to find different forms of food conservation that use physic or chemic changes with the aim of increase the life cycle of the product. Of these methods, the most used is the hot-air dehydration, which use air flux at high temperature and a specific velocity for extract the moisture of the food [1]. This process has as the core of interest the chamber, within of which the foods is positioned and where really occurs all the mechanism of moisture extraction.

Given the importance of the chamber in this type of systems, have been made different studies with the aim of establish the behavior of the hot air inside of this, giving place to models and simulation that show specific configurations for the develop of the dehydration[2]. The tool most used for this, is the Computational fluids Dynamic o CFD, in the which is possible observe the different contours for velocity and temperature in a discrete system [3],[4].

Works related with solar collectors have used CFD for find favorable configurations in the architecture and function of the chambers of dehydrations [5],[6],[7],[8] From these studies is remarkable the effect observed in the contours of the velocity and temperature when the position of the elements was changed, since this determined the air over the food [9],[10].

Some studies of hot-air dryers is focus to identify who change the contours of heat respect to the number and positions of the boundary conditions [11]. Whit this information is possible to observe the candidates to optimization and make robust control[12].

MATERIALS AND METHODS

The CFD simulations is focus in the resolution of the differential equations systems by numeric methods, in general, based in the laws of mentum, energy and mass conservation, of the which is obtained the equation for continuity of Newtonian fluids (Ec. *1*), this is applied over discrete domains with a boundary conditions established [13] [14].

$$\frac{\partial(u * \phi)}{\partial x} + \frac{\partial(v * \phi)}{\partial y} + \frac{\partial(w * \phi)}{\partial z} = \Gamma \cdot \nabla^2\phi + S_\phi \qquad \text{(Ec. 1)}$$

Where u,v y w are the cartesian velocities of the fluid, ϕ the represent the material concentration transported, ∇ is the Laplace operator, Γ is the coefficient of diffusivity and S_ϕ is the source term.

For the resolution of this equation is necessary make a discretization of the system, the which consist in set finite volumes of control and make the needed physic relationships [15]. Generally, this prosses is make by division of the volume in some parts with a polyhedric shape.

The dehydration system discussed in this work belong to the group of systems that use hot air as the principal actuator, in particular, to the systems that implement a dehydration chamber to store the product while the flux air is applied. (watch **Figure 1**).

For this work is set the parameters of design in relation to the capacity of dehydration of 10kg per cycle, for pieces of food with a long of 5cm, width of 5 cm and a high of 1cm as maximum values and an air velocity of until 0.5m/s. with these values was founded the dimensions of the trays and de chamber.

Assuming the density of most of food as a value like the density of the water, is possible identify the mass of each piece. Whit this, a mass of 25g was calculated and was determinate that 400 pieces of food are needed to reach the operational parameters.

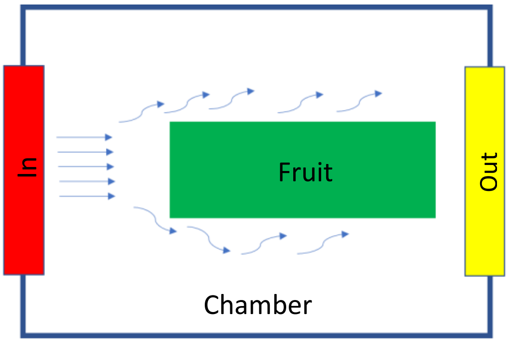

Figure 1. Scheme basic of the function for a chamber of dehydration by hot air.

Defining 10 as the number of available trays, it was determined that for each of this correspond 40 pieces of fruit. Whit these data, was defined that the dimensions of the tray are 540mm of large by 335mm of width leaving a contour of 20mm as structural member and that, it is possible to obtain a maximum temperature over the fruit of 315K with a velocity of 0.2m/s. The tray is made with 304 stainless steel to satisfy the food management requirements of the resolution 683 of 2012 (watch **Figure 2**).

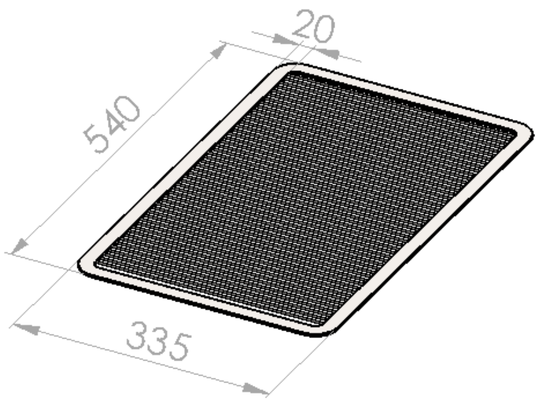

Figure 2. Design and dimensions of the trays.

After setting the trays dimensions, it is proceeded to the design of the chamber. For this, it is set a constant volume for the dehydration chamber that will change of partial form with the configurations available.

The general dimensions for the chamber are 600mm of long, 350mm of width and 500mm of high, these values allow the positioning of the trays in a vertical arrangement with a separation of 40mm (look **Figure 3**). The design starts from the geometries proposed in solar dryers, which benefits the temperature distribution inside the chamber [16].

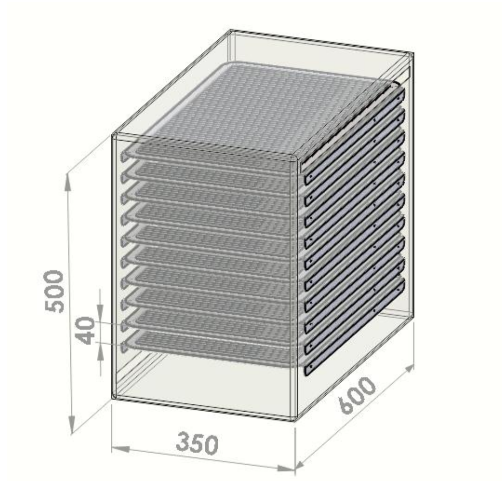

Figure 3. General dimensions of the dehydration chamber.

Although the geometry of the chamber has been changed, the volume will stay relative constant. With this, is possible to calculate the energy needed to heat the chamber, to identify the heat exchanger required. The heat necessary to increase the air temperature inside the chamber can follow the relation propose in the equation *(Ec. 2)*, which define that a system with a heat (Q_a), will increase the temperature (T) proportional to the heat capacity (Cp) and the fluid mass (m).

$$Q_a = Cp\ m\ \Delta T \qquad \textit{(Ec. 2)}$$

Applying the equation *(Ec. 2)* to a fluid volume of 0.105 [m^3], is possible find the heat that the system will need to increment the air temperature from 293[K] to 330[K]. Knowing that the heat capacity of air is 1012 [$Jkg^{-1}K^{-1}$] the heat take a value of 3931J or 3.72 [BTU]. Similarly, it is need define the heat sufficient to eliminate the moisture from food, for this it was assumed that dehydration occurs by evaporation using the equation *(Ec. 3)*.

$$Q_{ev} = \lambda\ M \qquad \textit{(Ec. 3)}$$

Where Q_{ev} is the heat needed to evaporate the food moisture, λ is the latent heat for evaporation of the water (2255 kJ/kg), M is the mass of the water in evaporation (in this case this value was the 95% of the fruit). With these values is defined the heat needed of 21422 kJ o 20304 BTU.

Hence, the total heat will be the sum of the heat for evaporation and the sensible heat of the air volume inside the chamber, that will be 20307 [BTU]. With this value the exchanger is selected taking in to account that, the system will receive the energy though the hot fluid for heat the air inside the chamber. For these features is choose a water-air exchanger with fins, with a capacity of 29000 BTU from an inlet of hot fluid at180°F (ver **Figure 4**).

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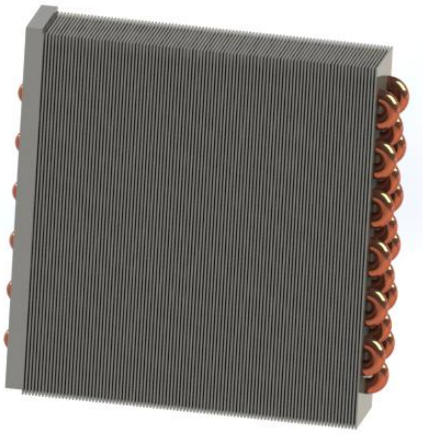

Figure 4. CAD design of the water-air heat exchanger.

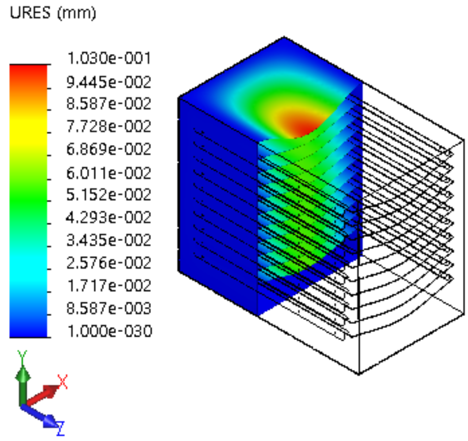

Figure 6. Simulation of the mechanic demands over the covers and the trays.

RESULTS

To find a sufficient and available design for the dehydration process object of this work, was necessary to complete a CFD simulations for the proposed cases. These simulations were performed in the tools of SolidWorks® Simulation and Flow simulation. The mesh for each simulation was different and computed automatically based on its complexity.

According with this, the first simulation corresponds to the verification of the mechanic resistance, all this, contemplate an initial load due to the 10Kg of fruits and a temperature of 330K. this simulation allow verify the if the system can support the process of dehydration.

With the aim of evaluate the operative conditions of the chamber, a simulation of the convective process domain by the heat exchanger is proposed. This simulation seek define the contours for the temperature and the velocity for the air inside the chamber, with which is possible identify and avoid the computational load for the futures simulations. According to the above, the simulation of the chamber with the exchanger was executed, the which had an inlet of air at environment temperature, a constant wall temperature of 340K for the pipes in the exchanger and the a range of velocities of 0.1 $[ms^{-1}]$ to 0.5$[ms^{-1}]$ (watch **Figure 7**).

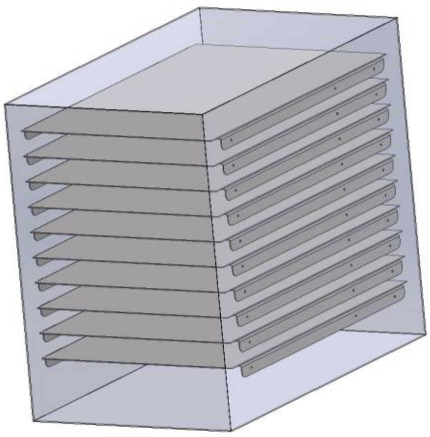

Figure 5. Design of the dehydration chamber.

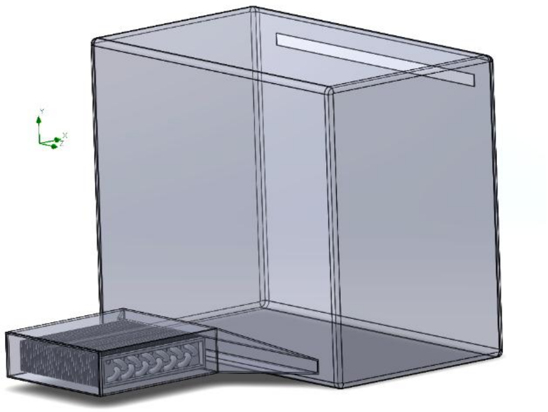

Figure 7. CAD of the simulation for the convective heat.

As shown in the **Figure 5**, the simulation has in to account the sheet that covers the chamber, the supports and a simplification of the trays with food. In this simulation is possible to observe the deformations of a chamber which uses a number 18 sheet of stainless steel. The maximum deformation obtained was 0.1 [mm] (watch **Figure 6**).

In the **Figure 8** is represent the average temperature inside the chamber product of the simulation, in this is possible to observe how the inside temperature of the chamber change invers to the inlet velocity constant. From this data is remarkable the magnitude of temperatures according the velocity between 0.1 $[ms^{-1}]$ and 0.2 $[ms^{-1}]$.

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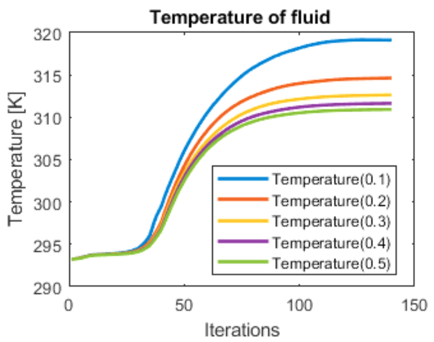

Figure 8. Chart of the temperature of the fluid in the steady state simulation.

The contours for the velocity are shown in the **Figure 10**, in these is possible to appreciate the homogeneity of the temperature through of the volume. How is observed, exist a decrease of the velocity in some parts, this is due to the loss in the velocity of the flux produced by the solids inside the chamber, which produced a uniform elevation of the heat.

These contours show how is produced the current between the inlet to the outlet at high velocity, which favors turbulence inside the chamber that mix the air during the trajectory.

This is beneficial to the temperature, but it is a disadvantage for the moisture extraction, because of this will avoid the exit of the moist air easily.

Different configurations of the dehydration chamber were proposed to evaluate the its performance. The number and position of the outlets as well as the orientations of the trays were set (watch **Figure 9**).Theses simulations has as boundary conditions, the hot air at velocity of 0.2m/s through an area of $0.011m^2$ which mean a flow of $0.00286\, kg\, s^{-1}$ at temperature of 314K. with the objective of identify the behavior of the air

Figure 9. Set of the trays inside the chamber; trays oriented to (a)-5°, (b)0°, (c)5°.

In these simulation, the side outlets was varied between 2 possible forms for make 3 different scenarios, the first one is when the outlet is only for the left side, the second one when is for the right side, and the last one when is both sides. How can be observe in the **Figure 11**, this variation does not have a significant effect over the contour of the temperature.

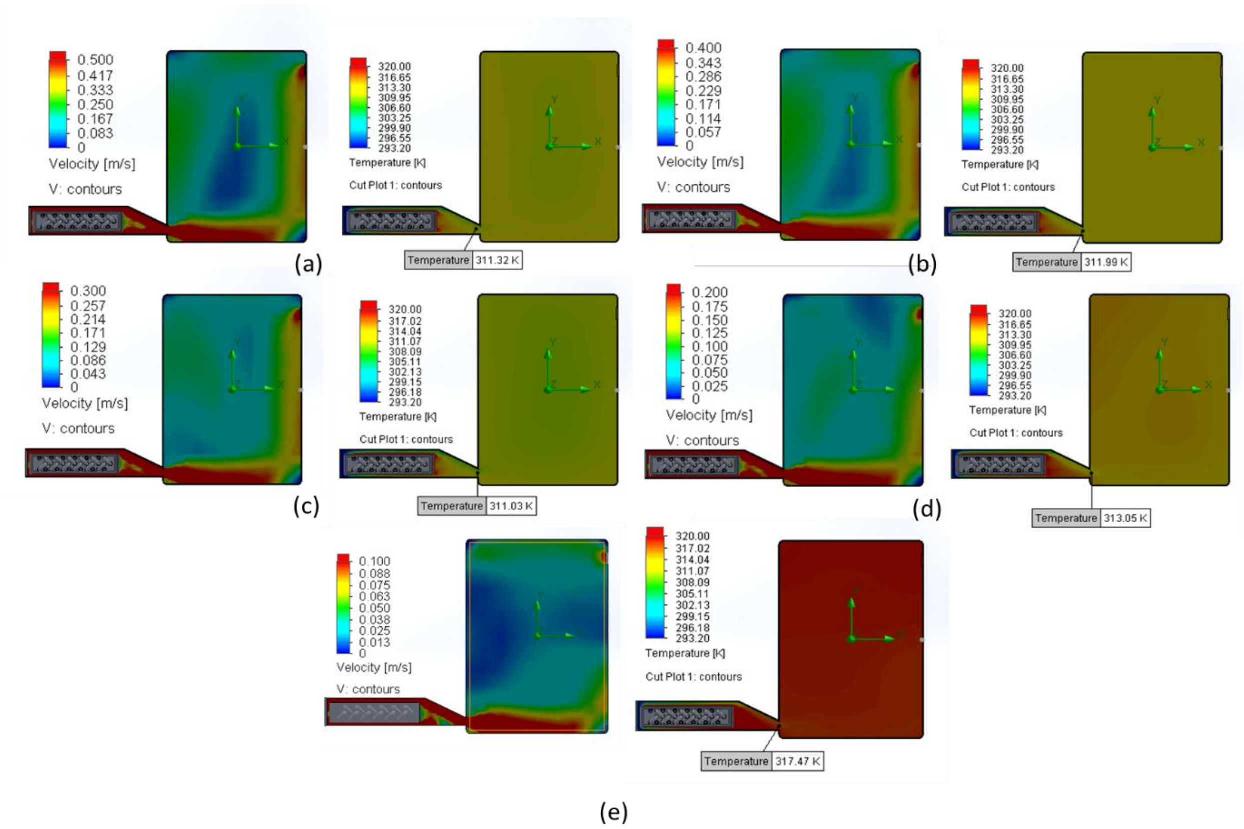

Figure 10. Contours of temperature and velocity for different inlets speeds; (a) 0.5 m/s ,(b) 0.4 m/s ,(c) 0.3 m/s, (d) 0.2 m/s ,(e) 0.1 m/s.

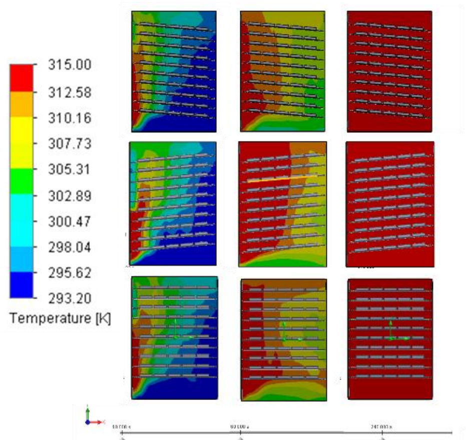

Figure 11. scheme of the contours of temperature in the inside of the chamber at10s 60s y 240s.

With respect to the velocity, it was observed that the variation of the angle in the trays orientation, favors the velocity near the inlet. Hence, it was appreciated that the first pieces of fruit in the tray, take the majority of the turbulence and backflows. This is show in the

Figure 12, from which is notable that the configuration with an outlet in the same direction of the inlet flow, have more zones without velocity.

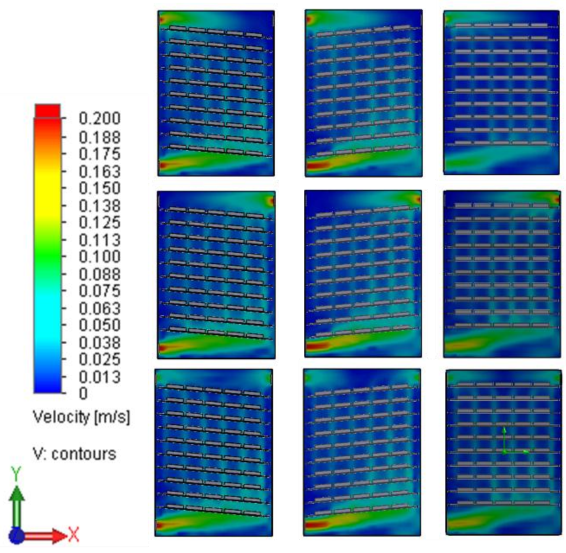

Figure 12. Velocity contours in different configurations.

CONCLUSIONS

From this works is concluded that the thermal system of de dehydration chamber, related with the contours of temperature, is sensitive to the velocity, only in the beginning of the process, so with the pass of time the distribution of temperature inside chamber is homogeneous and stable. Similarly, the change in the dispositions of the trays does not have a significant effected over the thermal contour near to the food.

Also, is concluded that the direction of the air flux is a relevant factor in the design of hot air dehydrations systems, due to the connection with the turbulences generations that avoid the adequate food moisture extraction obtain a partial dry. This can be avoid choosing more of one outlet with an opposite direction of the air flux.

Comparing the results obtain is concluded that, the configuration with a best performance is the option with an outlet in both sides and horizontal trays inclination. Furthermore, the simulation of the mechanical efforts showed that the system can support all the process with this configuration at a maximum of temperature of 315K and a velocity of 0.2m/s.

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