**Contemporary Engineering Sciences, Vol. 10, 2017, no. 15, 703 - 711**
**HIKARI Ltd, www.m-hikari.com**
**https://doi.org/10.12988/ces.2017.7767**

# CFD Numeric Simulation to Obtain the Proper Parameters of Corozo Drying (Bactris Guineensis)

**Jonathan Fabregas Villegas, Henry Santamaría De La Cruz,**
**Fabio Bermejo Altamar and Wilman Orozco Lozano**

Grupo de Investigación GI Fourier, Facultad de Ingeniería Mecánica
Universidad Antonio Nariño, Colombia



**Abstract**

A characterization of the process of drying the corozo (Bactris guineensis) fruit behavior, performed by numerical simulation CFD was carried out. A variation of the drying process input conditions was made choosing the temperature as variable, analyzing its effects on the drying of the corozo when being implemented in the ranges between 50 °C and 85 °C with specific relative humidity conditions of 76% and drying rate of 1 m/s, for which the convective heat transfer models and phase change models were used. The curves of the drying process of the biomass were obtained for each temperature, profiled the speed and moisture loss inside the biomass. The results obtained by numerical simulation are compared with those obtained experimentally showing reliability of this practice. The drying process of the corozo can be used for its preservation as food and its use as a source of unconventional energy generation.

**Keywords**: Corozo (Bactris Guineensis), Food drying, CFD, Drying curve

## 1. Introduction

In the agricultural sector the drying processes are carried out in order to preserve the food and products derived from the crop, since the moisture content directly affects the decomposition of the products and in their increase of mass which causes overweight on the transportation process. At the present time products and residues obtained from crops are used as sources of energy generation from their use as fuel, which can be obtained from biomass by means of thermochemical conversion or biochemical conversion. For a good use of the energy potential of the biomass we must have the characterization of its components and among them the moisture content, which affects the usable energy potential, therefore it is advisable to carry out drying operations to reduce this excess of moisture present in the product substances of the crop [1, 2]. In researches such as those of [3]. They carried out a case study for the drying process using as work substance air in which they use to measured the effects of the convection in an experimental way in different furnaces and drying chambers changing the speed and temperature of drying, we obtained the results showing the curves of drying processes, Diffusive coefficients, activation energy, among others. In the study by [4]. They developed a research on the kinetics of drying using as biomass quince slices doing experiments where they varied the drying temperature, the speed and the relative humidity, adjusting methods implemented in the literature, which allowed obtaining the results of the diffusive coefficients curves of drying, Activation energy of the process and determined the sorption isotherms of the quince slices. While [5]. They developed a study by numerical modeling by CFD of the mechanisms of heat and mass transfer for the process of drying to forced convection in rectangular objects. Obtaining approximated results to the results obtained experimentally. [6] They performed an analysis to identify the behavior of the heat transfer coefficient by convection and the mass transfer coefficient when a drying process is performed on a plate with porosity, in their study the conjugated behavior between heat and mass transfer of the variables using CFD computational tools was analyzed. [7-12] they conducted modeling studies to analyze the heat and mass transfer in drying processes and applied to ceramic materials, wood and food. Analysis that were developed by CFD modeling and were validated in an experimental way, concluding with good results and approximations indicating that the drying and mass transfer operations are quite nourished when applying CFD analysis.

Taking that into consideration this study was developed to perform a characterization of the drying process of the corozo (Bactris guineensis) using the CFD tools for analysis.

## 2. Materials and methods

The amount of moisture/humidity present in the atmospheric air for each relative humidity at a given temperature from which, in the form of a function, Fig. 1 is obtained, and the model or method is determined for calculating the amount of moisture/humidity in the air at a given temperature directly tied to the relative humidity as shown in Table 1.

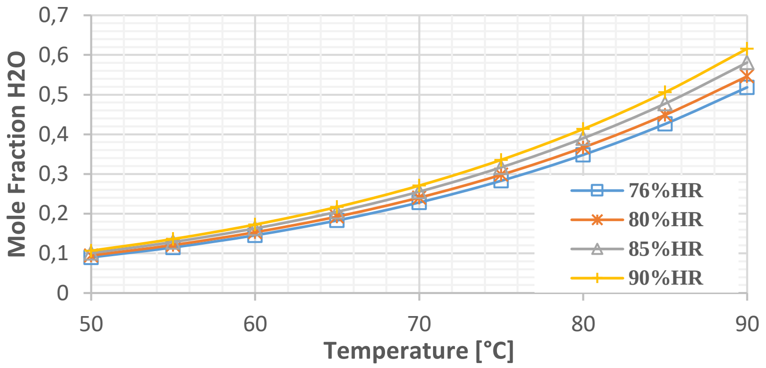


Fig 1. Moisture content in the drying agent

| Relative Humidity [%] | Molar Fraction [H2O] | $R^2$ |
|---|---|---|
| 76 | Fr m.H2O=1.04435E-02e^(4.37323E-02T) | 0.998706 |
| 80 | Fr m.H2O=1.09839E-02e^(4.37509E-02T) | 0.998713 |
| 85 | Fr m.H2O=1.16582E-02e^(4.37741E-02T) | 0.998723 |
| 90 | Fr m.H2O=1.23309E-02e^(4.37974E-02T) | 0.998732 |

Table 1. Regression models for moisture estimation in the drying agent

A modeling of the drying process of the biomass known as corozo (Bactris guineensis) was performed using the respective models for the mass transfer operations for porous media when the air with certain relative humidity is used as drying agent.

To do this, the energy models governed by the following equation were activated:

$$\frac{\partial}{\partial t}(\rho E) + \nabla\left(\vec{V}(\rho E + p)\right) = \nabla\left(k_{eff}\nabla T - \textstyle\sum_j h_j \vec{J}_j + \left(\bar{\bar{\tau}}_{eff}\,\vec{V}\right)\right) + S_h \tag{1}$$

Where the variable ρ is the density, E is the transmitted energy, p is the pressure, $k_{eff}$ is the effective thermal conductivity, $\vec{J}_j$is the diffusion speed and $S_h$ is the chemical energy of the process, if any.

For the evaporation and condensation methods, the Lee mass transfer models are activated as shown below:

$$\frac{\partial}{\partial t}(x_V \rho_V) + \nabla.\left(x_V \rho_V \vec{V}_V\right) = \dot{m}_{lV} - \dot{m}_{Vl} \tag{2}$$

Where $x_V$ is the steam volume fraction, $\rho_V$ is the density of the steam, $\vec{V}_V$ is the velocity of the steam and the terms $\dot{m}_{lV}$ , $\dot{m}_{Vl}$ are the mass flow per unit volume due to the evaporation and condensation of the substance.

## 2.1 Parameters and boundary conditions

Using as condition the porosity of the biomass, the viscous resistance values 1/a and inertial resistance C2 values are obtained, by means of the following equation and represented in Table 2.

$$a = \frac{{D_p}^2}{150}\frac{\varepsilon^3}{(1-\varepsilon)^2} \tag{3}$$

$$C_2 = \frac{3.5}{D_p}\frac{(1-\varepsilon)}{\varepsilon^3} \tag{4}$$

| Parts | Porosity | Viscous Resistance [1/m2] | Inertial Resistance [1/m] |
|---|---|---|---|
| Pulpa | 0.67 | 7.728E+10 | 851049604 |
| Almendra | 0.35 | 7.421E+11 | 1.176E+10 |

Table 2. Properties of the corozo (Bactris guineensis)

Once the volumetric meshing of the biomassic material and the drying agent is carried out, the boundary conditions are assigned, using interface surfaces between the drying agent and the biomass, assigning as input conditions the speed of the drying agent, the relative humidity in the drying agent, temperature ranges during the process, amount of moisture in the biomass samples, as shown in Fig 2 of modeling conditions.

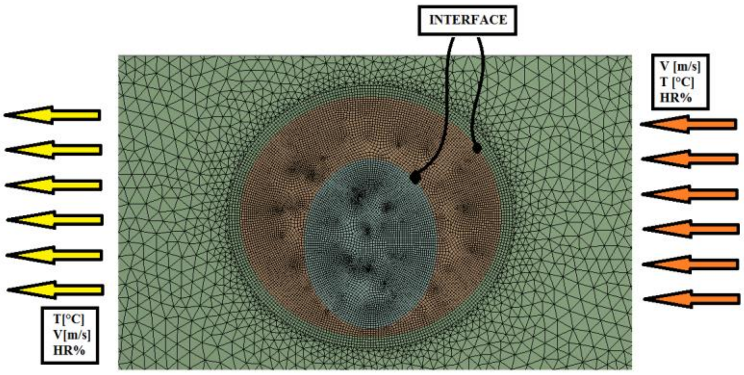


Fig 2. System boundary conditions

In order to perform the modeling tests, we identified the study variables that are the percentage of relative humidity % RH of 76%, the speed of the drying agent $\vec{V}$ of 1 m/s and the temperature T used in each test. Performing a total of 8 tests by increasing the temperature value from 50 °C to 80 °C.

## 3. Results and Discussion

Each of the tests results are obtained in the form of profiles, vectors, functions, the results corresponding to the variables of the process such as temperature, flow rate, moisture content, among others.

The readings obtained from tests carried out by changing the temperature by 5 °C from 50 °C to 85 °C are shown in Fig 3 below.

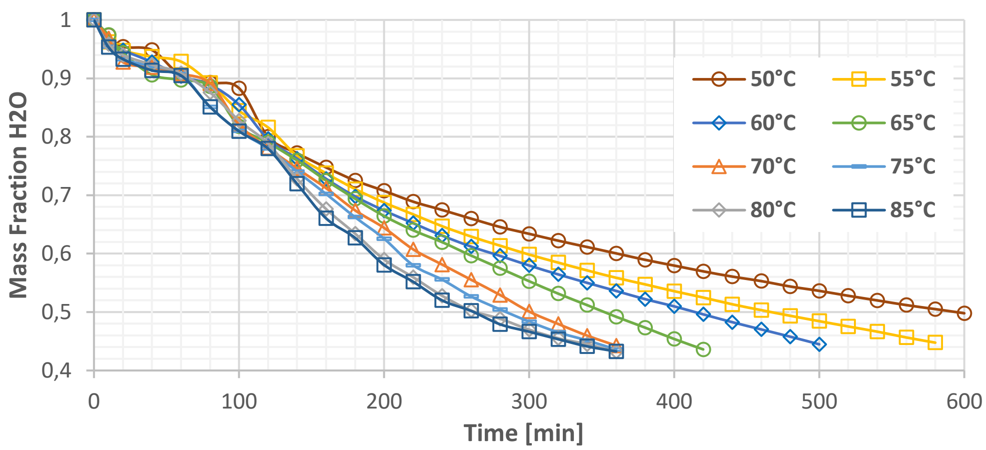


Fig 3. Corozo drying curves (Bactris guineensis)

From the previous figure, it is emphasized that at a higher temperature the equilibrium time of humidity loss is lower, whereas at a lower temperature the equilibrium time of humidity increases notably. In the intervals of 80 °C and 85 °C similar equilibrium times are obtained, which means that no increase in temperature is necessary from this point to decrease the equilibrium times for the drying of the biomass. The results obtained in Fig. 3 in the form of functions are shown in Table 3 below.

| Temperature °C | Molar Fraction [H2O] | $R^2$ |
|---|---|---|
| 50 | $\text{Frv. H20} = -5.36588E-12t^4 + 4.54145E-09t^3 - 5.91083E-07t^2 - 1.68082E-03t + 1.00080E+00$ | 0.995001 |
| 55 | $\text{Frv. H20} = -1.09237E-11t^4 + 1.14896E-08t^3 - 2.20360E-06t^2 - 1.41018E-03t + 9.92975E-01$ | 0.997584 |
| 60 | $\text{Frv. H20} = -2.24847E-11t^4 + 2.20130E-08t^3 - 5.19788E-06t^2 - 1.19061E-03t + 9.86444E-01$ | 0.997699 |
| 65 | $\text{Frv. H20} = -1.74264E-11t^4 + 1.50742E-08t^3 - 2.85763E-06t^2 - 1.48632E-03t + 9.88248E-01$ | 0.996221 |
| 70 | $\text{Frv. H20} = -2.85903E-11t^4 + 2.88277E-08t^3 - 8.02925E-06t^2 - 1.00823E-03t + 9.80737E-01$ | 0.997756 |
| 75 | $\text{Frv. H20} = -7.81937E-12t^4 + 1.70468E-08t^3 - 5.93577E-06t^2 - 1.20521E-03t + 9.79226E-01$ | 0.997248 |
| 80 | $\text{Frv. H20} = -6.55076E-11t^4 + 6.59580E-08t^3 - 1.87062E-05t^2 - 2.48655E-04t + 9.73427E-01$ | 0.996821 |
| 85 | $\text{Frv. H20} = -5.39504E-11t^4 + 5.55626E-08t^3 - 1.54129E-05t^2 - 6.26257E-04t + 9.73269E-01$ | 0.996934 |

Table 3. Regression models of the moisture content of the biomass

A validation was made by doing experimental tests and comparing them with the results obtained by numerical analysis by software CFD obtaining the results shown in Fig 4 below.

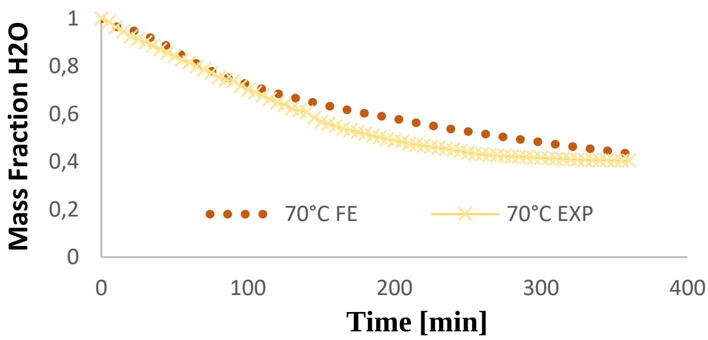


Fig 4. Comparison of experimental tests with CFD numerical simulation

From the previous figure we obtain the error range in percentage between the experimental process and numerically simulated, which for the whole of the curve 10% is generated and for the equilibrium moisture content and equilibrium time an error between maximum tests of 5% % with a deviation of 0.02 units of mass fractions between tests, showing a high acceptance of the practice of numerical modeling with experimental tests. The moisture loss profiles over time for the drying agent inlet temperature in the drying chamber of 80 °C are shown in Fig 5 below.

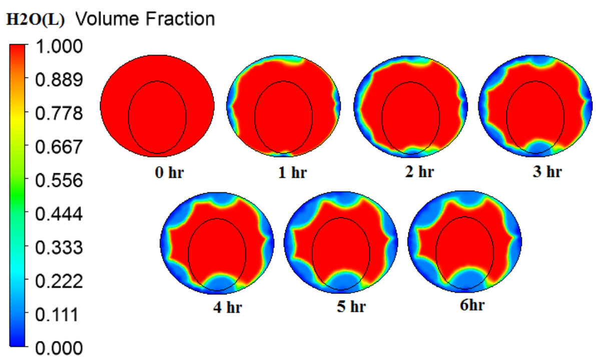


Fig 5. Corozo moisture content profiles (Bactris guineensis)

From the above figure it can be observed that from the 5th hour of the process to the 6th hour, the equilibrium zone for the loss of moisture of the biomass sample starts.

Since the geometry of the biomass has a semi-spherical shape the velocity profile of the drying agent is indicated as a cross-flow profile surrounding the sample in which it is observed in Fig 6 that the zones where the speed is increase are found to the sides of the biomass, and stagnation points in the post-biomass are present.

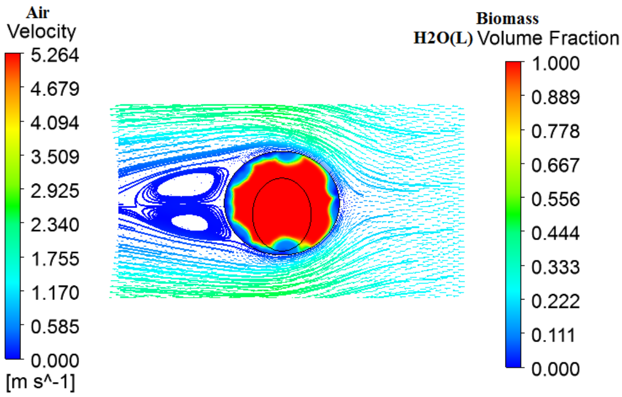


Fig 6. Speed and moisture content profile of the corozo (Bactris guineensis)

This points the loss of moisture content of the biomass to happen directly to the outer surfaces towards the back profile of the biomass.

## 4. Conclusions

The computer simulation of the drying of corozo (Bactris guineensis) was carried out, and from this the drying curves were obtained at different working temperatures of the drying agent and the curves were found to fit the traditional experimental phenomenon. The instability of the different curves shown in simulations before 120 minutes can be explained by the super-saturation of moisture in the surface of the fruit and subsequently the continuous decrease until the equilibrium moisture lis reached. It is point out that the best drying behavior was obtained between 80 °C and 85 °C, where the lowest equilibrium times and humidity of 360 minutes and 0.42 mass fraction respectively were obtained. A congruent behavior of the variation of moisture or fraction of water mass over time in the fruit shown with the same appearance as when the fruit is shrink and wrinkled in experimental processes.

The importance of this research is that it can predict the behavior of the drying process of this or other fruit that has similar characteristics to the corozo (Bactris guineensis), reproducing the drying process through the regression models obtained from the simulation.

## References

[1] M. Krokida, V. Karathanos, Z. Maroulis and D. Marinos-Kouris, Drying kinetics of some vegetables, *J. Food Eng.*, **59** (2003), no. 4, 391–403. https://doi.org/10.1016/s0260-8774(02)00498-3

[2] S. Babalis and V. Belessiotis, Influence of the drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs, *J. Food Eng.*, **65** (2004), no. 3, 449–458. https://doi.org/10.1016/j.jfoodeng.2004.02.005

[3] D. Tzempelikos, A. Vouros, A. Bardakas, A. Filios and D. Margaris, Case studies on the effect of the air drying conditions on the convective drying of quinces, *Case Stud, Therm. Eng.*, **3** (2014), 79–85. https://doi.org/10.1016/j.csite.2014.05.001

[4] A. Kaya, O. Aydin, C. Demirtas and M. Akgün, An experimental study on the drying kinetics of quince, *Desalination*, **212** (2007), no. 1–3, 328–343. https://doi.org/10.1016/j.desal.2006.10.017

[5] A. Kaya, O. Aydin and I. Dincer, Numerical modeling of heat and mass transfer during forced convection drying of rectangular moist objects, *Int. J. Heat Mass Transf.*, **49** (2006), no. 17–18, 3094–3103. https://doi.org/10.1016/j.ijheatmasstransfer.2006.01.043

[6] T. Defraeye, B. Blocken and J. Carmeliet, Analysis of convective heat and mass transfer coefficients for convective drying of a porous flat plate by conjugate modelling, *Int. J. Heat Mass Transf.*, **55** (2012), no. 1–3, 112–124. https://doi.org/10.1016/j.ijheatmasstransfer.2011.08.047

[7] T. Tsory, N. Ben-Jacob, T. Brosh and A. Levy, Thermal DEM-CFD modeling and simulation of heat transfer through packed bed, *Powder Technol.*, **244** (2013), 52–60. https://doi.org/10.1016/j.powtec.2013.04.013

[8] T. Defraeye, E. Herremans, P. Verboven, J. Carmeliet and B. Nicolai, Convective heat and mass exchange at surfaces of horticultural products: A microscale CFD modelling approach, *Agric. For. Meteorol.*, **162** (2012), 71–84. https://doi.org/10.1016/j.agrformet.2012.04.010

[9] A. Kaya, O. Aydin and I. Dincer, Experimental and numerical investigation of heat and mass transfer during drying of Hayward kiwi fruits (Actinidia Deliciosa Planch), *J. Food Eng.*, **88** (2008), no. 3, 323–330. https://doi.org/10.1016/j.jfoodeng.2008.02.017

[10] J. Smolka, A. J. Nowak and D. Rybarz, Improved 3-D temperature uniformity in a laboratory drying oven based on experimentally validated CFD computations, *J. Food Eng.*, **97** (2010), no. 3, 373–383. https://doi.org/10.1016/j.jfoodeng.2009.10.032

[11] T. Defraeye, B. Blocken and J. Carmeliet, Influence of uncertainty in heat-moisture transport properties on convective drying of porous materials by numerical modelling, *Chem. Eng. Res. Des.*, **91** (2013), no. 1, 36–42. https://doi.org/10.1016/j.cherd.2012.06.011

[12] J. Fabregas, H. Santamaría, F. Bermejo, W. Orozco and A. Bula, Obtaining Fruit-Drying Curves and CFD Analysis for Corozo (Bactris Guineensis), *Contemporary Engineering Sciences*, **10** (2017), no. 12, 569–577. https://doi.org/10.12988/ces.2017.7656

**Received: August 10, 2017; Published: September 10, 2017**