EXPERIMENTAL STUDY OF CONVECTIVE COEFFICIENT OF MASS TRANSFER OF AVOCADO (Persia americana Mill.)

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Abstract. *Most of all energy consumed worldwide comes from fossil fuels derived from petroleum. With the petroleum crisis in the 70 were sought new energy sources, among them renewable. One such source is biodiesel energy, organic matter originated from animal and / or vegetable. Among the various plant species is the avocado (Persia americana Mill.) showing great potential in the production of petroleum extracted from the pulp and the alcohol removed from the seed. The main obstacle for obtaining the petroleum is the high humidity found in the pulp, being necessary to the drying process, which involves the transfer of heat and mass. The aim of this study was to use the mathematical model represented by Newton's Law of Cooling to simulate the mass transfer on the surface of the avocado pulp during the drying process. The equation of the mathematical model was solved numerically and the method of least squares was identified convective coefficient of Mass Transfer. The dryer used in the experimental process was operated with air flow in the vertical, air flow average fixed 3m/s and temperatures of 50, 60 and 70º C. The scheme of the dryer used in the research is composed of the following equipment: centrifugal fan, which drives the air-drying; valve, which allows control of airflow; electrical resistance, used for heating air; the drying chamber, where enables measurement of temperature and relative humidity; support for smaller trays; trays smaller, where the samples of the pulp of the avocado are placed; exit of the air of drying for the environment. The result presented shows the ratio of moisture content as a function of temperature over time, where it is possible to also observe that how much bigger the temperature of drying, greater will be the Convective Coefficient of Mass Transfer of the avocado.*

Keywords: *Drying, Avocado, Biodiesel.*

1. INTRODUCTION

When one is about the matrix the national and world-wide energy, petroleum is certainly the main raw material. In the 70, there was the petroleum crisis, drastically affecting the world economy (ROSA and GOMES, 2004). Thus, there was a need to seek alternatives to petroleum. The demand for renewable fuels then underwent a progression. And biodiesel is an alternative to petroleum and its derivatives, already than its production is cheaper and the emission of pollutants is very small.

The raw materials for biodiesel production are diverse, such as vegetable oils, animal fats and waste petroleums and fats residual (SALVADOR, 2009). Vegetable oils and fats are composed of triglycerides, esters of glycerol and fatty acids, where the main sources for the extraction of vegetable oil are the oil plants such as: soybeans, castor beans, avocado, among others.

Search on oleaginous detaches the avocado (*Persia americana* Mill.) as a new alternative for the production of biodiesel, therefore this fruit presents in its pulp high values of substance grease, that constitutes one of the main components for the production of the petroleum, as well as alcohol in its seed, that is another important component for biodiesel.

Avocado (Persia americana Mill.) is fruit very humid and the drying if it makes necessary, as a stage in the production of biodiesel. The drying is seen as a process that involves both the heat transfer and mass, being able to modify of substantial form the quality and the physical properties of the product, depending on the method and conditions of this process (BROD, 2003).

The drying can be carried through of natural form, displaying the product directly to the sun or of artificial form using equipment as greenhouses and driers (PARK et al., 2001).

The simulation and project of the drying operation requires a mathematical model that represents the decrease in moisture during the drying process (MARIANI and MARTINI, 2003). Where the required energy is proceeding from an artificial drier that has the objective to heat air to evaporate the water of the food.

The equation that defines the mass transfer on the surface of the product is based on of Newton's law of cooling, presuming that during the drying, the conditions are isothermal and that the humidity transference is restricted the surface of the product (INCROPERA and DEWIT, 2006).

The convective coefficients of mass transfer were obtained through the method of least squares, which seeks to find the best fit curves of experimental data with predicted values.

2. MATHEMATICAL MODEL USED

On mass transfer by convection occurs a global movement of fluid that combines with internal diffusion, to promote moisture transport for which there is a concentration gradient on the surface of the product under review, generating a convective coefficient of mass transfer (h_m) which is based on Newton's Law of Cooling.

The equations defining the mass transfers on the surface of products for calculating the convective coefficient of mass transfer (h_m) are established by reference to a notion of surface conductance interpreted by a phenomenon known as boundary layer. Where it forms a thin layer of air flowing around the particle, so there is a balance of temperature and moisture between air and surface of the particle. The convective coefficient of mass transfer (h_m) depends on: the conditions in the boundary layer that is affected; of the nature of fluid motion and of the thermodynamic properties (INCROPERA and DEWIT, 2006). Therefore, the period of constant rate drying is represented by:

$$\overline{X} = h_m.A.(x - x_\infty) \tag{1}$$

Where:

$\overline{X}$: rate of mass transfer (g/s)
h_m: convective coefficient of mass transfer (m/s)
A: surface area of the sample (m^2)
$(x - x_\infty)$: mass concentration of the sample and air, respectively (g/m^3)

For the application of mathematical model in the drying the slice of the avocado, it is necessary to apply some boundary conditions:

- Initial condition: $t = 0$; $0<Y<L$; $X = X_0$
- Center: $t > 0$; $Y = 0$; $\frac{\partial X}{\partial t}=0$
- Surface: $t = \infty$; $Y = L$; $X = Xeq$

To validate the model, it is necessary to consider the following hypotheses:

- Convective Coefficient of Mass Transfer constant;
- Geometry as an infinite plate of thickness L;
- The moisture content external is unidirectional;
- Shrinking of the rejected product.

Solving Equation (1) by integration, obtain the external profile of moisture concentration in time, expressed as moisture content in dry basis, as shown in Equation (2):

$$MR = \frac{X - X_{eq}}{X_0 - X_{eq}} = Exp(t.h_m.A) \tag{2}$$

Where:

MR: ratio of the moisture content;
X: moisture in time (g/g);
X_{eq}: equilibrium moisture content (g/g);
X_0: initial moisture (g/g);
t: time (s);
h_m: convective coefficient of mass transfer (m/s);
A: surface area of the sample (m^2).

Statistical analysis is performed by calculation of relative mean error by Equation (3), which aims to assess whether the models used were or were not predicted (P <10%):

$$P = \frac{100}{N}\sum_{i=1}^{N}\frac{V_p - V_0}{V_0} \quad (3)$$

Where:

P = average relative error (%);
V_p = predicted values by the model;
V_0 = experimentally observed values;
N = number of experimental points.

3. RAW MATERIAL AND METHODOLOGY

3.1. Raw material

For this work were used avocados (*Persea Americana* Mill.) mature, of the quintal variety, purchased at fair central market of the city of Joao Pessoa, in Paraiba, deriving municipality of Conde, the same State.

The fruits were selected providing standardized samples according to: size, shape, coloration, firmness and degree of maturation.

3.2. Methodology

The procedure was performed at the Laboratory of Sciences and Food Technology of the Federal University of Paraíba.

The fruits were washed, peeled and cut into the shape of plates, using a knife and slicer (Tiemsen) and caliper rule for measuring (5.0 x 4.0cm) by 0.2cm thick.

The tests were performed in a fixed bed dryer operating at a temperature of 50, 60 and 70° C and drying air velocity of 3.0m/s. The weighing of the samples was performed every 15 minutes during the first hour of procedure and every 30 minutes until a constant weight, using semi-analytical balance (Marte). At the end of drying was held determination the dry mass of samples through greenhouse. All tests were done in triplicate.

In Figure (1) is presented the scheme of the dryer used in research that consists of the following equipment: centrifugal fan (1) which drives the air-drying; valve (2) which allows control of airflow; electrical resistance (3) used for heating air; the drying chamber (4) where enables measurement of temperature and relative humidity; support for smaller trays (5); trays smaller (6) where the samples of the pulp of the avocado are placed; exit of the air of drying for the environment (7).

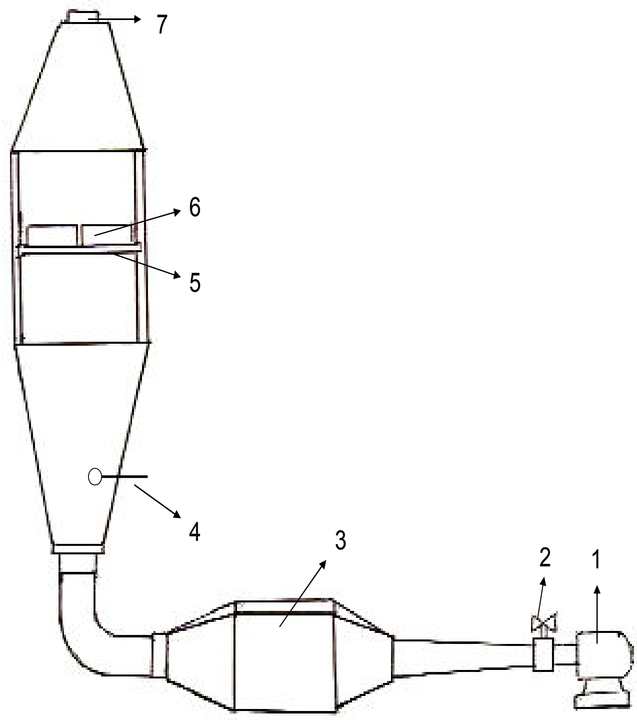

Figure 1: Schematic of tray dryer

The kinetics of convective drying was performed from the data dimensionless moisture content versus time of the process. The model described by Equation (2) was used to determine the convective coefficient of mass transfer.

4. RESULTS

The determination of convective coefficient of mass transfer (h_m) was calculated using the methodology of non-linear regression by the method of least squares, in possession of the experimental data of drying kinetics. It is observed that how much bigger the temperature of the drying process, greater will be the convective coefficient of mass transference, in significant terms, confirming as soon as this suffers to fort influence from the thermodynamic properties as, for example, the temperature (INCROPERA and DEWIT, 2006).

Table 1 shows the convective adjustment model for the temperatures of 50, 60 and 70°C as well as the correlation coefficient (R^2) and average relative error (P%) for the drying of the samples of *in natura* avocado.

Table 1. Adjustment of the model Convective for samples *in natura* avocado

T_{ar} (ºC)	$h_m \times 10^{-3}$ (m/s)	R^2
50	5.78	0.9948
60	6.38	0.9947
70	7.79	0.9888

With the increase of mass transfer coefficients of the slice of the avocado, it is observed that there is a reduction of moisture on the surface of it, which is called free water, thus enabling a time shorter drying process and consequently a lower operating cost for this process.

Statistically, show the values average relative error (P) less than 10% and correlation coefficient (R^2) around 1, indicating that Newton's model represents satisfactorily the kinetics of drying on the surface of the sample slice in natura avocado. Some researchers such as El-Aouar (2007) and Azoubel et al. (2008) used the average relative error (%P) and correlation coefficient (R^2) in order to evaluate if the mathematical models used in the process drying of fruits were or not predicted.

Graph of the ratio of moisture content as a function of temperature over time was plotted to examine the dependence of the convective model represented by Newton's Law of Cooling with the experimental. As shown in Figure (2).

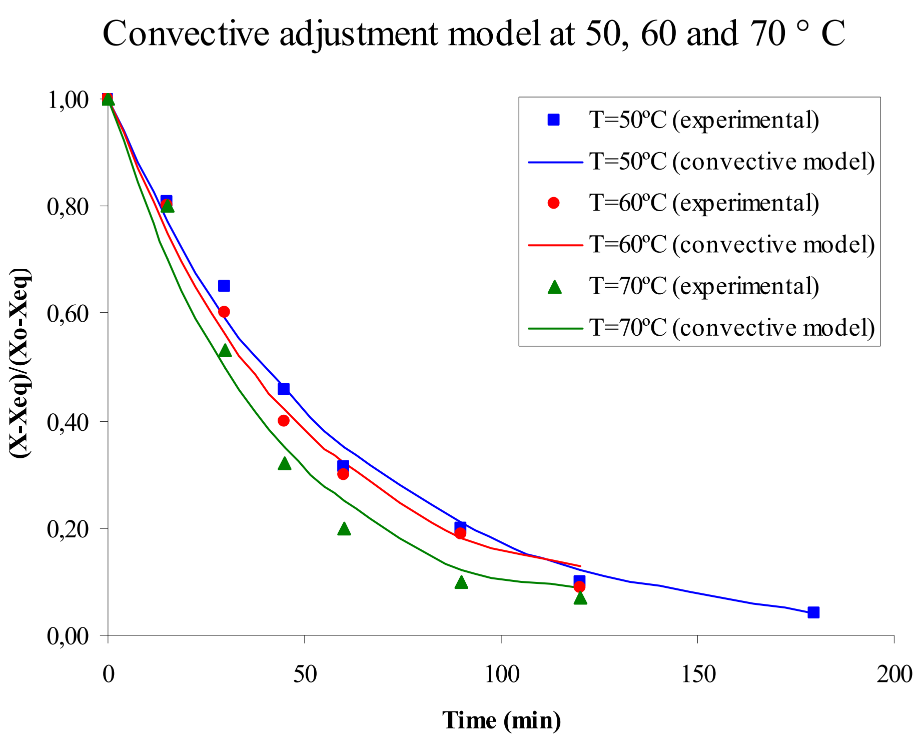

Figure 2: convective adjustment model

It is observed that in temperature for 50°C, The process lasted three hours and the mass loss initially presented in the first hour of drying occurs faster compared to the rest of the process. This is because the sample initially has a larger amount of available water on its surface, which is called free water. With increasing drying time, water inside the product that is known as bound water on, find a greater resistance to exit the sample, therefore the physical structure of the same it starts to have a new configuration, that is, its pores tend if to close to the measure that the sample continues in the drying process. Being thus, the output stream of internal humidity starts to be slower, thus making it difficult the end of the drying process.

Verifying the temperature of 60ºC it is possible to perceive that the loss of mass for the process reached a lesser time that the previous temperature, arriving the two hours of drying. It can also be observed that in the first hour of drying to free water over surface of the sample found little resistance for its removal, resulting in a bigger rapidity at the beginning of this process. Already from the first hour of drying, water connected to the physical structure of the avocado, rich in lipid content, finds a bigger resistance to be removed. Therefore drying done at 60°C proved to be faster than the previous temperature, thus proving that when increasing the temperature of the process drying time decreases and with this it there is a reduction in terms of energy it consequently and in financial costs.

The process of drying for the temperature of 70ºC, as it can be observed through Figure 2, demonstrates a similar behavior to the temperature of 60ºC, therefore the time of the process was also of two hours, although that the temperature increased in ten degrees.

The experimental analysis shows that for temperature 50°C, the experimental data fit the model represented by Newton's Law of Cooling thus proving that no significant interferences occur in this process. Similar behavior was observed for other temperatures obtained during the drying of the sample.

It is also verified in the experimental one that the model of Newton was capable to foresee the behavior of the convective drying for the sample of the slice of the avocado in the three temperatures of analyses. It is verified also on the experimental analysis that the model of Newton was able to predict the behavior of the convective drying of the slice of avocado at all temperatures studied. This is due to the fact that the parameters involved in the convective mass transfer, such as temperature and air velocity were controlled satisfactorily for drying, as shown by El-Aouar (2007), the drying of fruit by curves drying kinetic.

5. CONCLUSION

The convective model represented by the Law of Cooling of Newton got good adjustments to the experimental data of this study, being proven through the statistical data represented by the relative mean error (P) that was inferior 10%, as well as, of the correlation coefficient (R^2) next to one. Therefore, the convective model represented by Newton's Law of Cooling can be used to predict mass transfer on the surface of avocado (*Persia americana* Mill.) under the conditions used in this study.

6. ACKNOWLEDGEMENTS

The authors acknowledge the financial support provided by CNPq - National Council for Scientific and Technological Development.

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8. RESPONSIBILITY NOTICE