Thermal and Physical Properties of Parchment Arabica Coffee Beans

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Abstract

The thermodynamic and physical properties of parchment coffee beans in Veracruz (Mexico) have been evaluated as function of moisture content. The moisture content of the examined parchment ranged from 11.0% to 55.0%. The results indicate that the angle of repose, the bulk density, the specific heat and enthalpy depend mainly on moisture. Physical and geometric properties such as length, width, thickness and superficial flat and transversal areas are not dependent on moisture content but rather on the morphology of the beans.

Keywords: *Thermal and physical properties, drying, parchment coffee, morphology of coffee beans.*

Introduction

As other seeds also coffee needs to be dried after harvesting to reduce moisture content to the storage and market degree. Moisture content of coffee cherries at harvest time varies from 45% to 52%, but after the first phases of processing, that include removing the skin and pulp, fermentation and washing, this value can rise up to 56 %. For this reason, immediately after fermentation, the coffee, that at this stage is called parchment out of the name of the endocarp, must be dried up to about 11% of moisture content, either naturally or with artificial methods.

In order to optimise the process of drying and therefore also the necessary equipments, the thermal phenomena that take place in the process must be analysed, specially the behaviour of the coffee beans during conditioning.

The scope of this work is to focus on some physical and thermodynamic properties of parchment coffee during drying, and more specifically on density, repose angle, enthalpy and specific heat.

Literature review

In 1968 Thompson pointed out that relations between geometrical characteristics and moisture content of coffee beans vary during the drying process; Ghosh and Gancaja in 1970 analysed with more detail the relations between the three dimensions of coffee beans, pointing out the differences between *arabica* and *robusta* varieties, but didn't correlate them with the evolution of moisture content during the drying process. In 2000 Ciro asserted that there is no specific relation between the surface of the transversal area of parchment coffee beans and moisture content.

Abud in 1988 found a linear relation between density and moisture content of parchment coffee when the latter is above 14% and in 1989 Montoya suggested some models for describing physical properties, but only for the final part of the process, when moisture content is below 11%. In 1992 Brooker confirmed that knowledge of the physical and thermodynamic properties of coffee beans allows elaborating mathematical models relating drying process variables

Materials, Method and Experiments

This work has been carried out in Mexico, in a coffee farm in the Region of Córdoba-Huatusco, Veracruz State, an area with humid tropical climate (INEGI, 2000) with altitude of 750 m. The cultivation is carried on with traditional techniques based on manual harvesting and artificial drying with the use of a dryer "*Tipo Guardiola*" (figure 1).

Tests consisted in taking 10 samples of parchment coffee out of the dryer every 3 hours, during the whole drying process (24 h). Each sample, consisting of 250 seeds, was classified according to the actual morphological classification (Debernardi 2003) and for each kind main physical and geometrical measures were taken in order to determinate sizes, moisture content, density and angle of repose.

Finding of Physical Properties of Parchment Coffee

Moisture content (U)*:* it has been determined by weighting (ASAE 1996)

Length, width and thickness: Mean values have been calculated for 800 beans (10 beans for each sample) whose dimensions have were measured using a micrometer with a precision of $\pm$0,001 m. (Figure 2).

Angle of repose is the maximum slope, measured in degrees from the horizontal, at which loose coffee beans will remain in place without sliding and depends on the sliding friction of the grains among themselves. The experimental data have been obtained measuring the sliding angle of beans on an inclined steel plate.

Density has been determined by measuring the change in a volume of water after introducing a known mass of coffee beans.

Thermodynamic Properties of Parchment Coffee

The heat content of a chemical system is called the enthalpy *(H)*; this quantity indicates the tendency of a system to modify its physical status by absorbing or releasing heat. The enthalpy change (ΔH) is the amount of heat released or absorbed when a chemical reaction occurs at constant pressure.

The authors suggest that it is possible to evaluate main energetic aspects of coffee drying process by calculating the enthalpy of the air in the dryer (Cini, et al., 2000). In fact, knowing that the specific heat of dry air and of water vapour is respectively 0,24 and 0,46 kcal/(kg · ^{0}C) at constant pressure using the gravitational system of units, and that heat of vaporization is 595 kcal/kg when T is below 100 °C, enthalpy of humid air is:

$$H = 0,24 \cdot T + x \cdot 10^{-3} (595 + 0,46 \cdot T)$$

where:

T is the temperature of the air inside the dryer and consequently *0,24 T* and *0,46 T* are the sensible heat of the dry air and of the water contained in the air, while $x \cdot 10^{-3}$ is the ratio between the mass of the dry air and the water and depends on moisture content.

Therefore it is possible to evaluate the amount of heat needed for drying coffee beans since this operation is carried out at temperatures below 100°. This method consists in finding the amount of water that each kg of air can contain (the difference between the amount of water contained in saturated air and the amount of water contained in the air used for drying) at the temperature at which the process is carried out, the amount of water that must be removed from the mass of coffee and then to calculate the amount of air needed. The enthalpy of this amount of air allows finding the energy needed for the process.

For instance if the water to be evaporated is 500 kg, the temperature of the air 40 °C and its humidity 60%, the tables of air properties tell us that the amount of water contained in each kg of air is 28,4 g while at the same temperature the air is saturated with 48,4 g; each kilo of air can then remove 20 g of water and about 30 m^3 will be needed to remove the whole amount. The energetic input needed for the process will therefore be $[0,24 \cdot 40 + 48,4\ 10^{-3} (595 + 0,46 \cdot 40)] \cdot 30.000/1,2$ kcal.

Results

Table 1 shows the results of the measurements taken on various samples of coffee beans: the geometrical sizes of the beans remain almost constant during the process, meaning that moisture doesn't influence significantly the volume of parchment coffee beans.

The angle of repose instead decreases with moisture content as shown in table 2.

Table 2 also shows that there is a significant linear correlation (r = 0,99) between the moisture content of a mass of coffee and it's angle of repose: it is then possible to represent this relation through a simple interpolation model:

$Ar = 32,95 + 23 \cdot U$

where:

Ar = Angle of repose of parchment coffee (deg)

U = Moisture content of parchment coffee [%]

s.d. $\pm = 0,27$; $r^2 = 0,98$; $r = 0,99$; $(P<0,001)$.

In figure 3 the evolution of density is charted during the drying process: the initial mean value of density is 715,3 kg · m^{-3} while at the end of the process it drops to 400,7 kg · m^{-3}. Also in this case it has been possible to introduce a simple interpolation model:

$D = 321,3 + 720 \cdot U$

where:

D = Density of parchment coffee (kg/m3)

U = Moisture content of parchment coffee (%)

s.d. $\pm = 0,45$; $r^2 = 0,99$; $r = 0,99$; $(P<0,001)$.

This mathematical model works for the whole process, while the one proposed by Ciro ($D = 282,4 + 599 \cdot U$) (Ciro 2000) works only for the lower range of moisture content. Moreover the proposed models correspond to experimental values, while other models reviewed in literature (Ciro 2000, Ghosh and Gacanja, 1970) have been obtained by simulating the drying process.

The results of statistical analysis of the measured values together with the data produced by the model (which represents the correlation (r = 0,99) between moisture content and density during the drying process) show the need for considering density together with the other physical characteristics of coffee when designing or timing coffee dryers

Data concerning thermodynamic characteristics of parchment coffee are shown in table 3. It can be seen that after the 9th hour of drying the specific heat and enthalpy decrease and the process slows down and the operational capacity drops from 26,36 to 17,53 kg of $H_2O \cdot h^{-1} \cdot m^{-3}$. The slowing down of the process is caused by the diminished permeability of the parchment consequent to the closure of the pores that makes it more difficult for the moisture to reach the surface. In fact the differences in the composition of the endocarp and of the endosperm cause a different behavior during the process: parchment becomes more stiff because of its higher cellulose content, specially if drying is carried out at high temperatures, while the bean decreases its volume of about 10%. Consequently, although the external size of the bean doesn't vary, an air cushion is formed between endosperm and endocarp, which acts as an insolent, hence obstructing heat transfer to the inner tissues. This phenomenon increases while the bean becomes harder (Coste, 1980).

Data published by Kinch in 1967 are also shown: the use of a different variety of coffee with a different size is probably the cause of the differences with the data obtained by the authors.

Discussion

Geometric properties of parchment coffee do not vary significantly in relation to moisture content during the drying process.

The angle of repose of parchment coffee and its moisture content are linearly correlated: the angle of repose increases with moisture content.

When designing new coffee dryers physical and thermal characteristics of coffee beans must be carefully considered, since the optimal timing of "Guardiola" type dryers depends on the physical conditions of the product that is being processed. On this basis it has been possible to foresee an improvement of the process performances, as it will be described as soon as experimental data will be sufficiently reliable.

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Table

Table 1. Mean values of parchment coffee (C. arabica) dimensions; *(P < 0,001), CV = 1,35*

Time of drying (h)	U (%)	Φ_1 10^{-2} m	Φ_2 (10^{-2} m)	Φ_3 (10^{-2} m)
0	55,0	1,245	0,905	0,563
3	51,7	1,204	0,908	0,566
6	46,8	1,239	0,905	0,564
9	38,8	1,244	0,904	0,565
12	32,0	1,240	0,907	0,563
15	24,7	1,237	0,905	0,566
18	19,1	1,244	0,906	0,564
21	13,9	1,239	0,904	0,563
22,5	11,2	1,243	0,905	0,565

Table 2 Angles of repose (average) of parchment coffee (C. arabica), during drying process

Time of drying (h)	Moisture content (%)	Angle of repose (°)
0	55,0	45,4
3	51,7	44,8
6	46,8	43,5
9	38,8	41,3
12	32,0	40,4
15	24,7	38,5
18	19,1	37,7
21	13,9	36,1
22,5	11,2	35,2

Table 3. Variation in physical and thermodynamic characteristics of coffee beans during hot air drying (initial mass of coffee: 3.700 kg, initial volume: 5,2 m^3).

Time (h)	Moisture content (%)	Density ($kg \cdot m^{-3}$)	Density (Kinch) ($kg \cdot m^{-3}$)	Temperature of the mass of coffee (^0C)	Enthalpy ($kJ \cdot kg^{-1}$)	Specific Heat ($kJ \cdot kg^{-1}$)	Operational Capacity (H_2O removed) ($kg \cdot h^{-1} \cdot m^{-3}$)
0,00	55,0	715,321	512,124	20,000	20,158	3,605	0,00
3,00	51,7	691,715	503,703	25,500	18,804	3,489	16,29
6,00	46,8	656,665	491,072	30,400	17,598	3,315	20,46
9,00	38,8	598,867	470,700	35,700	16,294	3,035	26,36
12,00	32,0	550,797	453,401	39,200	15,433	2,797	17,53
15,00	24,7	498,579	434,756	39,500	15,359	2,540	15,30
18,00	19,1	458,521	420,514	40,100	15,212	2,344	9,86
21,00	13,9	421,324	407,249	41,200	14,941	2,162	8,01
22,50	11,2	400,655	400,436	42,400	14,646	2,068	7,58

Figure

Figure 1. Dryer "Tipo Guardiola" (Debernardi 2003)

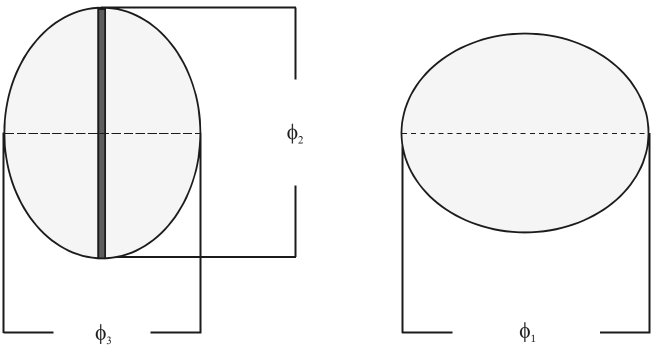

Figure 2. Geometrical dimensions of parchment coffee (Spiegel, 1968)

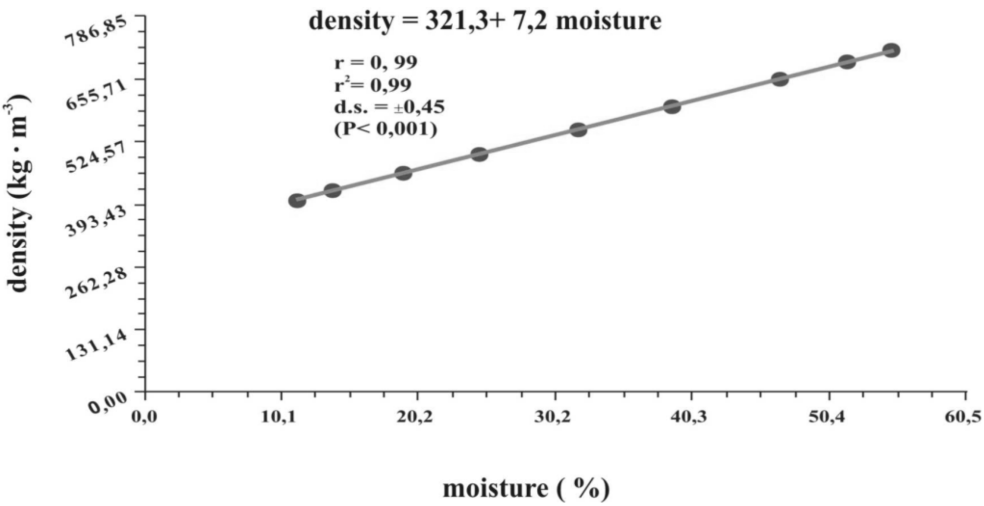

Figure 3. Relation between moisture content and density in parchment coffee