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PERFORMANCE OF MECHANICALLY SHAKEN INDIRECT CONTACT ATMOSPHERIC DRYER IN DRYING PASTELIKE MATERIALS

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Abstract - Pastelike materials are encountered in many technological processes in chemical, pharmaceutical, foodstuff and natural product industries. The most important factor in the drying of this type of materials is the nature of the moisture bonding that occurs. Because of the different characteristics of pastes, it is impossible to recommend a universal type of dryer for all of these materials. Some of the dryers available provide only indirect contact with the drying agent (heat) and also maintain constant moisture with a system of rotating paddles. We evaluated the performance of this type by studying the dryer kinetics curves for ground coffee under a variety of operational conditions of moisture load of material, temperature of the heating plate, intensity of the mechanical mixing of the moisture material, and initial moisture. The effects of these parameters (except for moisture) were studied using a 2^3 factorial design. According the analyses of the kinetics drying curves, was observed that the increase in the temperature of the plate and rotation as well as the decrease in the load facilitates more effective removal of moisture. In statistical analysis was determined that the load of the material and the heating plate temperature influence the final moisture content of the material and plate temperature modifies the final temperature of the solid. Also, was suggested linear models from the factorial design to describe the process of drying coffee grounds satisfactorily.

Keywords: contact dryer, performance, coffee grounds.

INTRODUCTION

Drying is used in a variety of industrial operations, with the objective to remove moisture, as vapor, from the material (Okada., 1987). Removal of this moisture reduces the volume and the mass of the product, making its transport and packing economically more advantageous. In addition, increases this storage time (Cook and Dumont, 1991). Pastelike materials are among those submitted to drying processes; these can be found in a variety of technological processes of chemical, pharmaceutical, and natural products industries (Strumillo et ii., 1983). According to these authors pastelike materials include hard pastes (such as pies and precipitates), soft pastes and sludge, suspensions, emulsions, and solutions. However, it is worth mentioning, that, due to the characteristics of the pastes, it is to recommend a standard dryer for paste processing and related operations. On the other hand, some of the dryers that can be used - are of the indirect contact type with mechanical shaking

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*To whom correspondence should be addressed where by the drying agent, heat, is supplied to a metallic surface and, consequently, to the material being dried. This type of equipment will be studied in the present work, in which coffee grounds after the first extraction were used, as the test material in a atmospheric drying chamber. The performance of the equipment is evaluated by analyzing the drying kinetics curves as a function of several operational parameters, such as wet load of material, temperature of the heating plate, mechanical shaking, and moisture of the material.

Drying by Indirect Contact

Contact drying in shaking bed is often used to dry granular materials such as pharmaceutical products, mineral powders, agricultural products or foodstuffs, and pastes (Gevaudan and Andrieu, 1991).

According to Sztabert (1989), the drying mechanism of this type of equipment depends on the temperature of the hot surface, the temperature and properties of the raw material and mechanical operation of the dryer and the pressure (vacuum or atmospheric).

MATERIALS AND METHODS

This work was conducted in the Laboratory of Processes in Porous Media (LPMP) of the School of Chemical Engineering (FEQ) at the State University of Campinas (UNICAMP).

Materials

For the purpose of this paper, coffee grounds after the first extraction on an express machine were used as the test material. The principal characteristics physics of the coffee are in Table 1.

The density was determined in gas picnometer Accupyc 1330 and porosity in porosimeter Autopore III 9400, both were producing for Micromeritics Instrument Corp. The particle diameter was used such as Maialle and Menegalli (1996).

Table 1: Physics characteristics of the coffee grounds.

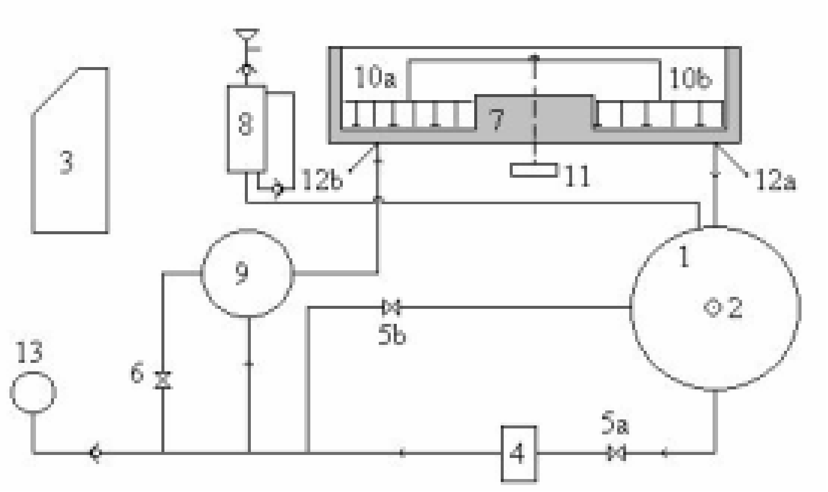
ρ_s (kg/ m^3)	ε_p	d_p (m)
1.3271	0.121	0.0007

Equipment

The apparatus used in this work is illustrated in Figure 1. This unit consists of a stainless steel cylindrical drying chamber exposed to the atmosphere with 0.24 m diameter, 1.5 cm thickness and 0.11 m^2 drying area having an internal heater device, through which silicone oil is circulated at 350cP.

The equipment is isolated with rock wool and corrugated aluminum. The drying chamber is connected to the oil container (1) (Figure 1), which is coupled to two electrical resistance of 750W each (2). The oil is heated by these electrical resistances, which are controlled by the control panel (3), and a gear pump (4) circulates the heating fluid. Two valves (5a, 5b) control the pressure of the circulation device pump; one of these (5b) operates partway-open and is located after the gate valve by-pass. This by-pass (6) sends oil to the container or heater device (7). The equipment has a replacement oil container (8) and an oil distribution container (9). The shaking system consists of a continuous flow motor (11), a connection shaft, and a scraper, which is controlled by a voltmeter. The drying system also contains type T thermocouples (12a, 12b), installed at the input and output of the oil container. Measurement of pressure is monitored by a manometer (13) coupled to the line.

The wet material to be used in the dryer is weighed on model C&F semi-analytical balance, with a precision of 0.1 g. Loads used for determination of moisture were weighed on a model BG400 Gehaka analytical balance, with a precision of 0.001g. Moisture content was determined by the oven method at 104 ±5ºC for 24 hours. This method was carried out in a model 315SE Fanem oven. The temperature of the heating plate was recorded by a type T digital thermometer from IOPE Therm with a precision of 0.1ºC.



1) Silicone oil container
2) Electrical resistance to heating
3) Control panel
4) Gear pump
5) 5a and 5b- valve controls
6) Bypass
7) Heater device
8) Replacement oil container
9) Sub-container oil for distribution
10) 10 a and b- Agitation system
11) Continuum current motor
12) 12 a and b- Type T thermocouples
13) Manometer.

Figure 1: The schematic diagram of the dryer.

Experimental Procedure

Initially the temperature of the heating surface was adjusted by a resistance monitored by a control panel. If took two hours to reach the stationary regime in the drying chamber. Then, when the variation in the temperature of the heating surface was about 0.5°C, the regime was considered permanent. The criterion for drying time take into account the time for total removal of the moisture with weight 0.5 kg, i.e., when the moisture is keep constant.

Once the stationary regime was achieved, the wet material, whose mass had been previously measured, was added to the drying chamber. At the same time the shaking system, whose revolution had also been previously fixed, was activated. Samples were collected in the drying chamber every 5 min in same place, because the less moisture until the material temperature was practically constant. At the end of the period an some of the material homogenous was collected in a small, previously weighed container and the small container with material was weighed and put in the oven at 104±5°C. After 24 hours the sample was taken out and weighed again and the moisture removed (d.b.) determined by the difference in mass as follows:

$$X = \frac{\text{mass}_{\text{wet}} - \text{mass}_{\text{dry}}}{\text{mass}_{\text{dry}}} \qquad (1)$$

Factorial Design

The strategy of the experiments was defined by means of a 2^3 factorial design generating a total of eight experiments. This design was used to verify to what extent the three independent variables, load of the material, temperature of the heating plate, and agitation speed, would be influence the response variables X_{final} and $T_{\text{p,final}}$.

The three independent variables used in this design were coded in the following way:
Var cod = +1 (highest level of the variable)
Var cod = -1 (lowest level of the variable)

The originals variables chosen to experimental and their levels are show in Table 2.

To analyze the trust worthiness and application of the models, three approaches were used: standard errors, probability (ANOVA), and regression coefficients.

Table 2: The originals variables chosen to experimental and their levels.

Originals variables (notacion)	Levels	
	Low (-)	High (+)
Temperature heating plate (T_w)	75°C	95°C
Moisture load of material (W_0)	0.5 kg	1.0 kg
Intensity of the shaking system (n)	20rpm	40 rpm

RESULTS

Nine assays were carries out in the laboratory. Drying kinetics was studied using five selected experiments. The experimental conditions adopted to this studied are presented in Table 3 for further analysis, where $T_{p,0}$ is the initial temperature of the particle, T_w ,the temperature of the heating plate, W_s the material load, X_0, the initial moisture of the material, and n the rotation of the mixing device.

Figures (2) to (5) are the experimental kinetics drying curves in the form of moisture of the material on a dry weight basis expressed in kg of H_2O/kg of dry material for the time (fixed at 1h for all the experiments). It can be verified that for all curves only surface moisture is removed from the material. It can also be observed that initially the material is cohesive (until the fourth point of the curves). Starting at the fourth points the material behaves like powder. It can be seen in Figure 2 that this modification is faster as the temperature difference between the drying agent and the material to be dried becomes higher (when the temperature of the plate is 95ºC). So, this should result in a larger removal moisture. Considering the effect of material load (Figure 3), it can be seen that the moisture reaches about 0.13 d.b with the lighter load, while for the heavier load it reaches around 0.6 d.b. The difference between these values is due to the smaller amount of processed material. When the mixing velocity is increased, a small tendency towards a quicker drying appears, which tends to show that shaking provides on time of contact of the material with the warm surface (Figure 4). However, it can be observed that moisture removal with time varies in the same proportion for different values of initial moisture (Figure 5).

Table 3: Experimental conditions.

Assays	X_0 (d.b)	T_w (ºC)	W_s (kg)	n (rpm)
01	1.5	70	1.0	20
02	1.5	95	1.0	20
03	1.5	95	0.5	20
04	1.5	95	1.0	40
05	1.75	95	1.0	40

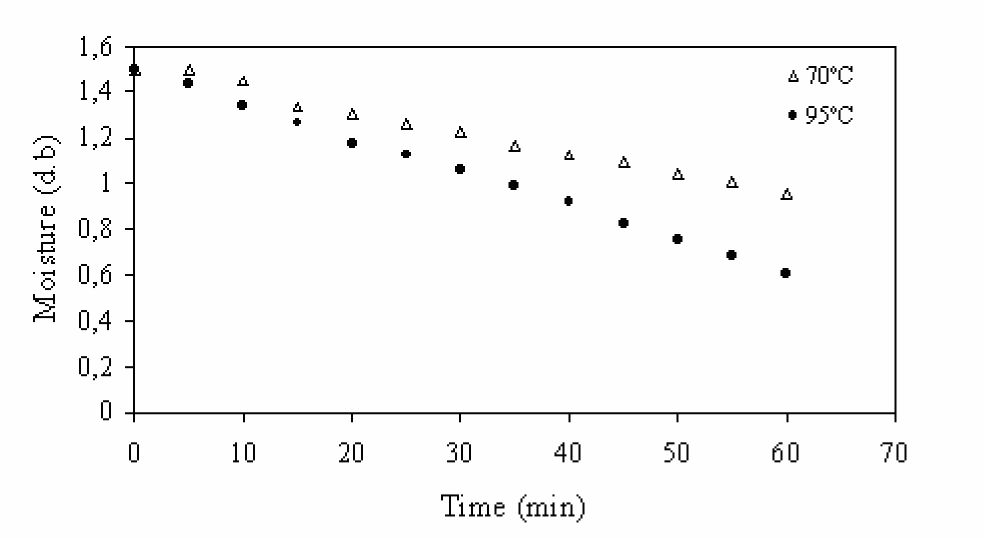


Figure 2: The influence of temperature of the heating plate.

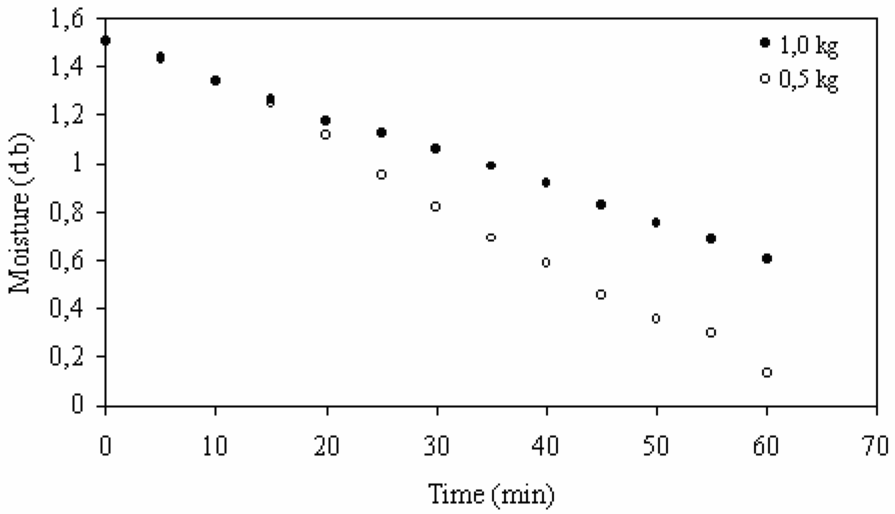


Figure 3: The influence of load material (on a dry basis).

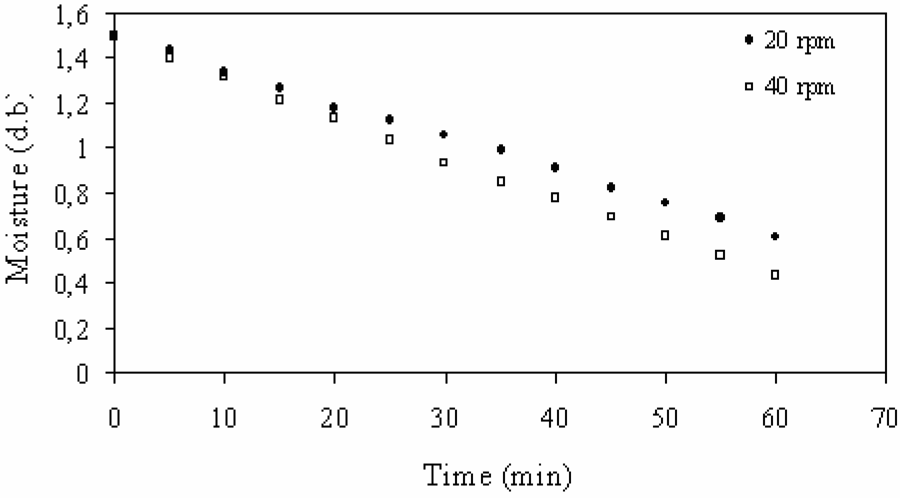


Figure 4: The influence of mixing velocity.

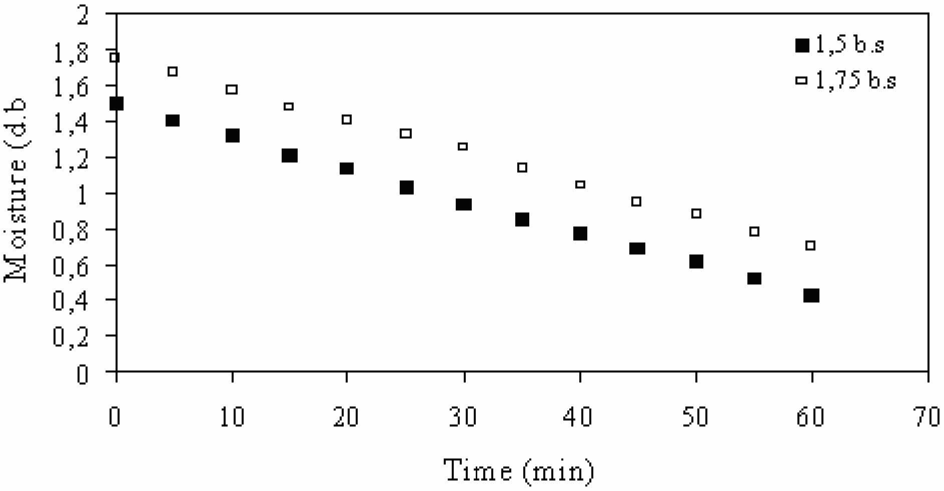


Figure 5: The influence of initial moisture of the material.

As mentioned previously, a 2^3 factorial design was adopted in this work. In agreement with this design, the original variables, T_w, W_s and n, coded at their respective levels for each experiment, as well as the values obtained experimentally for response X_{final} (final moisture of the material) and $T_{p,final}$ (final temperature of the particle) in the drying process, can be founds in Table 4.

Starting from experimental results, a statistical analysis was conducted with the aid of the software Statistica 5.0® with the purpose of evaluating which of the variables, independent or combined, influences X_{final} and $T_{p,final}$ in a period of 1 h of drying. As a result of the analysis the values of the estimated effects of each variable and their iterations with the respective deviation pattern, as shown in the Tables 5 and 6, were obtained.

Table 4: Experiments Matrix and results of the factorial design of experiments.

uns **o**	**Codified variables**			**Response**	
	T_w	W_s	n	X_{final} (d.b)	$T_{p,final}$ (°C)
1	-	-	-	0.52	52.0
2	+	-	-	0.13	62.7
3	-	+	-	0.95	50.9
4	+	+	-	0.60	68.1
5	-	-	+	0.45	56.6
6	+	-	+	0.019	65.7
7	-	+	+	0.95	52.0
8	+	+	+	0.43	66.3

Table 5: Estimate of the effects for the response variable X_{final}.

Effects	Estimated values +\-errors	T (student)	P. Level
T_w	-0.42+\-0.033	0.097	0.050*
W_s	0.45+\-0.033	-12.67	0.046*
N	-0.09+\-0.033	13.64	0.22
T_wW_s	-0.013+\-0.033	-2.76	0.76
T_wn	-0.052+\-0.033	-0.39	0.36
W_sn	0.003+\-0.033	-1.57	0.94
Mean	0.51+\-0.017	30.48	0.02*

Table 6: Estimate of the effects for the response variable $T_{p,final}$.

Effects	Estimated values +\-errors	T (student)	P. Level
T_w	12.82 +\-0.325	39.46	0.02*
W_s	0.075+\- 0.325	0.23	0.85
n	1.73+\-0.325	5.30	0.12
T_wW_s	2.923+\-0.325	9	0.07
T_wn	-1.13+\-0.325	-3.46	0.18
W_sn	-2.08+\-0.325	-6.38	0.098
Mean	59.29+\-0.1625	364.84	0.0017

Analyzing the p. levels values in Tables 5 and 6, it can be verified that for the response variable X_{final}, the independent variables (T_w and W_s) are statistically significant, i.e., their values are into of the significant level ($p<0.055$), while, for variable $T_{p,final}$, only the temperature of the plate is significant. These results, however, have to be confirmed for a confidence level of 94.5%. That is why, the statistical parameter Pr (probability) from the variance analysis is used, as shown in Tables 7 and 8.

Based on the statistical parameter Pr (probability), the influence of variables T_w and W_s on X_{final} and T_w on $T_{p,final}$ to be confirmed and the no significant effects are considered to be aleatory experimental errors.

According to the results in Tables 7 and 8, a linear statistical model for the responses, X_{final} and $T_{p,final}$, is proposed. The coefficients of these models can be found in Tables 9 and 10.

Table 7: Analysis of variance (ANOVA) for the variable X_{final} .

Effects	Sum of square	Degrees of freedom	Mean square	F Test	Probability
T_w	0.357300	1	0.357300	161.0902	0.050055
W_s	0.414183	1	0.414183	186.362	0.046504
n	0.017012	1	0.017012	7.6698	0.220598
T_wW_s	0.000335	1	0.000335	0.1513	0.763866
T_wn	0.005492	1	0.005492	2.4764	0.360401
W_sn	0.000021	1	0.000021	0.0096	0.937816
Errors	0.002218	1	0.002218	-	-
Total (Correlation)	0.796562	7	-	-	-

R^2= 0.99722

Table 8: Analysis of variance (ANOVA) for the variable $T_{p,final}$.

Effects	Sum of square	Degrees of freedom	Mean square	F Test	Probability
T_w	328.9612	1	328.9612	1557.213	0.016129
W_s	0.0112	1	0.0112	0.053	0.855615
n	5.9513	1	5.9513	28.172	0.118553
T_wW_s	17.1112	1	17.1112	81.000	0.070447
T_wn	2.5313	1	2.5313	11.982	0.179038
W_sn	8.6112	1	8.6112	40.763	0.098908
Errors	0.2113	1	0.2113	-	-
Total (Correlation)	363,3888	7	-	-	-

R^2= 0.9942

Table 9: Regression coefficients for X_{final}.

Parameter	Coefficients
Constant	0.50835
T_w	-0.21135
W_s	0.227525
n	-0.0461
T_wW_s	-0.00648
T_wn	-0.0262
W_sn	0.001625

Table 10: Regression coefficients for $T_{p,final}$.

Parameter	Coefficients
Constant	59.2875
T_w	6.4125
W_s	0.0375
n	0.8625
T_wW_s	1.4625
T_wn	-0.5625
W_sn	-1.0375

These models are described by equations (2) and (3) as a function of the variables that had a significant influence on the responses X_{final} and $T_{p,final}$, in accordance with the regression coefficients presented in Tables 8 and 9. The correlation coefficients of 0.9972 for X_{final} and 0.9942 for $T_{p,final}$ suggest that these linear models represent the experimental data satisfactorily.

$$X_{final} = 0.508-0.21T_w+0.23W_s \quad (2)$$

$$T_{p,final} = 59.29+6.41T_w \quad (3)$$

CONCLUSIONS

Conclusions drawn on the influence of the operational parameters (load of the material, temperature of the heating plate, and rotation) on the drying process, based on the statistical analysis and on the results of the experimental drying kinetics curves, are as follows:

1) In accordance with the analyses of the kinetics drying curves, it can be observed that the increase in the temperature of the plate and rotation as well as the decrease in the load facilitates more effective removal of moisture.

2) By means of the statistical analysis one can determine that the load of the material and the heating plate temperature influence the final moisture content of the material and plate temperature modifies the final temperature of the solid.

3) It can be verified that the linear models from the factorial design describe the process of drying coffee grounds satisfactorily.

NOMECLATURE

d_p	particle diameter, m;
n	rotation of the mixing device, rpm;
t	drying time, min;
$T_{p,0}$	initial temperature of the particle, ºC;
$T_{p,final}$	final temperature of the particle, ºC;
T_w	temperature of the heating plate, ºC;
X	removed moisture content of the material, kg/kg;
X_0	initial moisture content of the material on a dry weight basis, kg/kg;
X_{final}	final moisture content of the material on a dry weight basis, kg/kg;
W_s	material load, kg;
ρ_s	density, kg/m^3
ε_p	porosity.

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