DRYING OF SPENT COFFEE GROUNDS IN A CYCLONIC DRYER

Jefferson Luiz Gomes Corrêa[1], Johnson Clay Pereira Santos[2], Bruno Elyezer Fonseca[3], Ana Gabriela da Silva Carvalho[4]

(Recebido: 14 de novembro de 2012; aceito: 1 de julho de 2013)

ABSTRACT: Spent coffee grounds is a byproduct from the soluble coffee company. Besides its use as animal feed or lipid source, it presents a high potential as biofuel. Whatever the application, to be useful, the product has to loose great part of its moisture content. The drying of spent coffee grounds in a cyclonic dryer was studied in the present work. Based on a experimental design, the effects of temperature of the air (T_a) (59 to 271 ºC) and of the ratio mass flow rate of spent coffee grounds to mass flow rate of air (W_c/W_a) (0.1 to 3.6) on the moisture reduction (M_r) and average residence time of the particles on the cyclonic dryer (APRT) were studied. It was observed an inverse relation between M_r and the ratio W_c/W_a and a direct relation between M_r and T_a. Regarding the APRT, it presented an inverse relation to W_c/W_a. Additionally, the characterization of the spent coffee grounds was performed with respect to the centesimal composition, density and granulometric distribution. It was observed increasing the density and particle size with moisture increasing. It was shown that the cyclone could be an efficient dryer for particulate solids with the advantages of high moisture reduction within short residence time.

Index terms: Heat-mass transfer; biomass; physical characterization of spent coffee grounds: gas-solid flow.

SECAGEM DE BORRA DE CAFÉ EM UM SECADOR CICLÔNICO

RESUMO: *O processo de secagem em um secador ciclônico foi estudado para borra de café, um sub-produto da indústria de café solúvel. Com base em planejamento experimental, os efeitos da temperatura do ar (T_a) (59 a 271 ºC) e a razão vazão mássica de borra de café, por vazão mássica de ar (W_c/W_a) (0,1 a 3,6) , na redução do teor de umidade (M_r) e no tempo de residência médio das partículas no secador ciclônico (APRT) foram estudados. Foi observada uma relação inversa entre M_r e a razão W_c/W_a e uma relação direta entre M_r e T_a. Com relação ao APRT, esse apresentou uma relação inversa com relação a W_c/W_a. Adicionalmente, a caracterização da borra de café foi feita com relação à composição centesimal, densidade e distribuição granulométrica. Foi observado um aumento na densidade e no tamanho de partículas com o aumento do teor de umidade.*

Termos para indexação: *Transferência de calor e massa, biomassa, caracterização física da borra de café, escoamento gás-sólido.*

1 INTRODUCTION

Brazil has a large biomass production and good potential to utilize byproducts from the soluble coffee, sugarcane, paper and wood industries, among other agricultural residues (LORA; ANDRADE, 2009; MUSSATTO et al., 2011a; SILVA et al., 2009; SOCCOL; VANDENBERGHE, 2003). The use of biomass as biofuels offers the promise of numerous benefits related to energy security, economics and the environment. Biofuels generally results lower emissions than those of fossil based engine fuels (DEMIRBAS, 2009).

The spent coffee grounds is a biomass which can be used for solid state cultivation, animal feed (LEIFA; SOCCOL; PANDEY, 2008; SOCCOL; VANDENBERGHE, 2003), lipid source for cosmetics (RIBEIRO et al., 2013) or may be used direct as a fuel or raw material to produce biodiesel, feedstock for ethanol and as fuel pellets (KONDAMUDI; MOHAPATRA; MISRA, 2008; MURTHY; NAIDU, 2012; XU et al., 2006, 2008; ZUORRO; LAVECCHIA, 2012). In the soluble coffee industry, for each ton of final product, 0.91 ton of spent coffee grounds are produced, with moisture level of 80% (wet basis, w.b.) that is usually pressed to be burn. The dry product presents calorific power of about 25,000 kJ kg^{-1} (SILVA et al., 1998). Such amount is enough to supply 60% to 80% of the coffee processing plant

[1]Universidade Federal de Lavras/UFLA - Departamento de Ciência dos Alimentos/DCA - Cx. P. 3037 - 7.200-000 - Lavras - MG jefferson@dca.ufla.br
[2]Universidade Federal de Lavras/UFLA - Departamento de Ciência dos Alimentos/DCA - Cx. P. 3037 - 37.200-000 - Lavras - MG engenheiroa@yahoo.com.br
[3]Universidade Federal de Lavras/UFLA - Departamento de Ciência dos Alimentos/DCA - Cx. P. 3037 - 37.200-000 Lavras - MG - brunoelyezerfonseca@yahoo.com.br
[4]Universidade Federal de Lavras/UFLA - Departamento de Ciência dos Alimentos/DCA - Cx. P. 3037 - 37.200-000 Lavras - MG - anagabrielaeng@yahoo.com.br

itself, in terms of energy needs (CENTRO DE PESQUISA EM ENERGIA ELÉTRICA - CEPEL, 2000). For higher burning efficiency of biomass in the boilers, co-firing, pyrolysis or for gasification, it is important to have the moisture level reduced (RATNADHARIYA; CHANNIWALA, 2009; SILVA et al., 1998; SOSA-ARNAO; NEBRA, 2009; WERTHER et al., 2000; XU et al., 2006; ZHANG et al., 2010). As pointed in a previews work (SILVA et al., 1998), there is a lack on the data of properties of spent coffee grounds. There is also a lack on data of drying of spent coffee grounds.

The number of works concerning drying of spent coffee grounds is low (SILVA; CORRÊA, 2005). The drying of this product was developed in rotating fluidized bed and pneumatic dryer (ADANS; DOUGAN, 1985; NEBRA; SILVA; MUJUMDAR, 2000; SILVA et al., 1998; VIOTTO; MENEGALLI, 1992). On one hand, it is difficult to compare these works because of the different conditions used in each case. On the other hand, it can be said that drying in cyclones presents the advantages of homogeneous conditions of transport of the particles and final moisture content (NEBRA; SILVA; MUJUMDAR, 2000). Traditionally used to clean gases from particles (CHU et al., 2012; JUNG; PARK; KIM, 2009), the cyclone is a reasonable dryer for agricultural residues like sugar cane bagasse, spent coffee grounds and tomato pomace residues (CORRÊA et al., 2004a; NEBRA; SILVA; MUJUMDAR, 2000; OLIVEIRA et al., 2011; SOSA-ARNAO et al., 2006). However, for its higher efficiency in the drying process, its geometry should be adjusted aiming a longer residence time of the particles, and, consequently, higher moisture reduction (BUNYAWANICHAKUL et al., 2006; CORRÊA et al., 2004a, 2004b; NEBRA; SILVA; MUJUMDAR, 2000; OLIVEIRA et al., 2011).

This work aims to study the drying process and the average residence time of spent coffee grounds in a cyclone which geometry intended for drying. The effects of air temperature and ratio between mass flow of spent coffee grounds and the mass flow of air on the moisture reduction and average residence time of particles were accessed. Physic characteristics of the material were also determined.

2 MATERIAL AND METHODS

2.1 Material

The spent coffee grounds was kindly supplied by Indústria de Café Solúvel Brasília, located at Varginha, MG, Brazil.

2.2 Characterization of the Material

The centesimal composition, density and granulometric distribution of the spent coffee grounds were determined. All tests were performed in triplicates and the results are their average.

Centesimal composition: The crude protein was obtained based on semimicro-Kjeldahl method (KJELDAHL, 1883). The nitrogen level was converted into crude protein using the 6.25 factor.

The lipid content was determined according to the Soxhlet intermittent method (BRUN et al., 2009), based on lipid extraction by petroleum ether. After the extraction and solvent removal, the amount of lipid was determined gravimetrically.

The ash content was determined by calcinating the samples at 550 to 600ºC. The NFE (nitrogen free extract) was obtained by mass balance.

Density: The density was obtained with toluene as solvent in a 50 mL pycnometer (MOHSENIN, 1986).

Moisture Content: Moisture content was determined in drying oven at 105 ºC until constant weight (BRASIL, 2005).

Granulometric Analysis: The granulometric distribution of the samples was obtained using the standardized Tyler sieve method (FOUST, 1982), with the following set of sieves: 4; 8; 14; 28; 35 and 48 mesh. The influence of moisture content was also evaluated.

2.3 Experimental design

The experimental conditions (Table 1) were set according to the central composite experimental design (RODRIGUES; IEMMA, 2009). The independent variables were: solid flow to air flow ratio (V_1) and drying air temperature (V_2). Mass flow rate of air was maintained constant at 8.12×10^{-2} kg s^{-1}. The results obtained in the experimental design were obtained considering 90 % of confident interval and alfa (statistical criterium of significance) equal to 0.10.

TABLE 1 - Experimental conditions of drying trials of spent coffee grounds using cyclonic dryer following the central composite experimental design.

Test	V_1	V_2
1	3.1 (1)	240 (1)
2	0.6 (-1)	90 (-1)
3	3.1 (1)	90 (-1)
4	0.6 (-1)	240 (1)
5	0.1 (-1.41)	165 (0)
6	3.6 (1.41)	165 (0)
7	1.8 (0)	271 (1.41)
8	1.8 (0)	59 (-1.41)
9	1.8 (0)	165 (0)
10	1.8 (0)	165 (0)
11	1.8 (0)	165 (0)

V_1 represents the ratio spent coffee grounds mass flow to air mass flow [-], V_2, the air temperature [ºC].

2.4 Drying of spent coffee grounds

The drying trials were performed in an experimental system (Figure 1) composed by a blower, a heating system based on electrical resistances, an electric belt conveyor, a Venturi feeder and a cyclone. The air was admitted in the system by a blower (VEC, model 5ta 500 especial, 5 SCV, 5.000 RPM, pressure 1.000 mm ca, volumetric flow rate 30 $m^3 min^{-1}$). The duct that links the blower to the heater was a PVC pipe with 4 pol diameter. From the heater to the final of the system, thermal insulation was used. The particle flow was set according to the belt conveyor speed and the amount of spent coffee grounds collected. The flow of heated air was set using a frequency inverter and measured with a manometer attached to an orifice plate previously calibrated. The temperature was measured using calibrated thermocouples. The cyclone dimensions are shown in Figure 2. More details of the experimental systems can be found at Oliveira et al. (2011) and Santos (2009). The room air conditions were temperature, 25.4 ºC and relative humidity, 63 %.

The variation on moisture content was analyzed by the concept of moisture reduction, given by Equation 1.

$$M_r = \frac{X_i - X_f}{X_i} \tag{1}$$

where M_r corresponds to the moisture reduction, X, moisture content (wet basis, w.b.) and the sub indexes i and f to the initial and final conditions, respectively.

2.5 Average particle residence time (APRT)

The determination of the APRT was performed according to the *hold up* method (CORRÊA et al., 2004b; OLIVEIRA et al., 2011). The residence time, t_{res}, Equation 2, is given by ratio between the remaining mass of solids in the cyclone (m_{rem}) to the solid mass flow (W_p). The remaining mass of solids is measured when both solid feeding and blowing air is turned off simultaneously.

$$t_{res} = \frac{m_{rem}}{W_p} \tag{2}$$

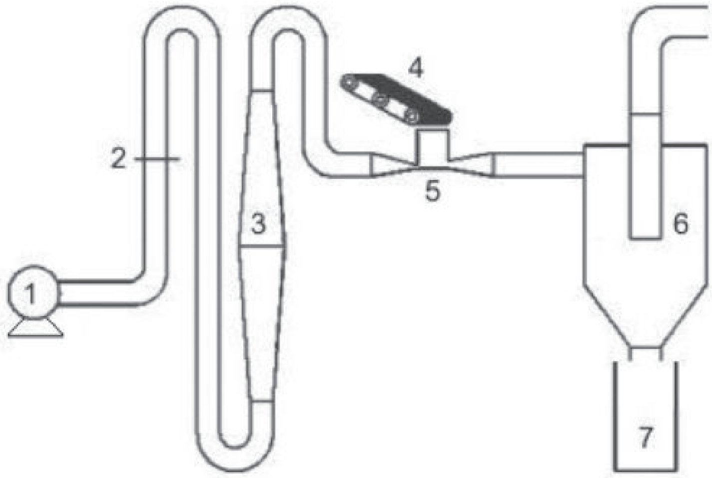

FIGURE 1 - Experimental setup. (1) Blower; (2) Orifice Plate; (3) Heater; (4) Electrical Conveyor Belt; (5) Venturi Feeder; (6) Cyclone; (7) Solid Collector

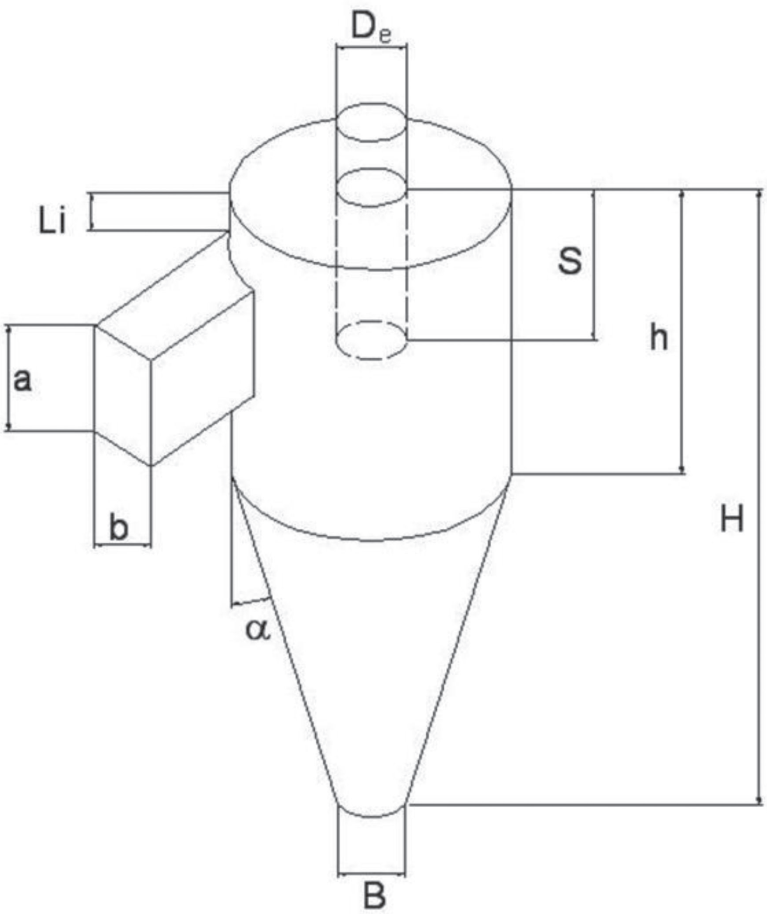

FIGURE 2 - Characteristic dimensions of a cyclone. De = 0.16 m; S = 0.50 m; Li = 0.15 m; a = 0.056 m; b = 0.25 m; h = 0.73 m; B = 0.10 m; H = 1.20 m; α = 41°

3 RESULTS AND DISCUSSION

3.1 Characterization of the material

Centesimal Composition: The centesimal composition of the spent coffee grounds used in the present work is presented on Table 2.

The percentage of the components presented in the spent coffee grounds obtained in the present work are close to the ones found by Ravindranath et al. (1972) that determined the crude protein, oil and crude fiber levels as 14 to 14.8%, 7.9 to 14% and 19.7 to 22.1%, respectively. As pointed by Mussatto et al. (2011b), the differences in the chemical composition of the spent coffee grounds may occur according to the variety of beans utilized, and the roasting and extraction processes that they were submitted. It is important to note that, in this condition, it is obtained in the soluble coffee industry, the spent coffee ground presents high moisture content. When a biomass is used as a fuel, the reduction of the moisture content causes an increase on the calorific value of the calorific value of the final product making the energy conversion more efficient (SOSA-ARNAO; NEBRA, 2009).

Granulometric analysis: The results of the granulometric analysis according to different moisture levels are presented in Table 3.

The size ranges of spent coffee grounds with larger mass fraction were obtained between the 1.20 mm (14 mesh) and 0.60 mm (28 mesh) sieves. Similar results were obtained by other authors (SILVA et al., 1998; VIOTTO; MENEGALLI, 1992). The higher moisture content, the larger mean particle diameter obtained. The smaller particles remain together because there is a great attraction between the wetted particles, resulting in larger particles (SILVA et al., 1998).

Density: Regarding the density variation due to moisture level, it was observed (Figure 3) that density decreases as the moisture level increases, what can be explained by the fact that the particles swallow, conferring them lower density compared to the dry solid. After a given minimum density, the density starts increase as the moisture levels increase, due to the increase in water mass fraction. The data obtained were fitted with a second order polynomial equation, Equation 3, with $r^2 = 0.94$.

TABLE 2 - Centesimal composition of the spent coffee grounds

Component	Percentage (%)
Moisture content (wet basis)	56.7
Ether Extract	15.1
Protein	4.5
Fiber	19.1
Ash	0.6
NFE*	4.0

NFE ia nitrogen free extract, *Obtained by mass difference

TABLE 3 - Granulometric analysis of the spent coffee grounds

	Sieve opening [mm]						
	4.7	2.3	1.2	0.6	0.4	0.3	0.0
X (w.b) [%]	Retained mass fraction [%]						
56	17	11	14	26	17	8	7
60	11	33	34	20	3	0	0
65	14	43	32	10	0	0	0

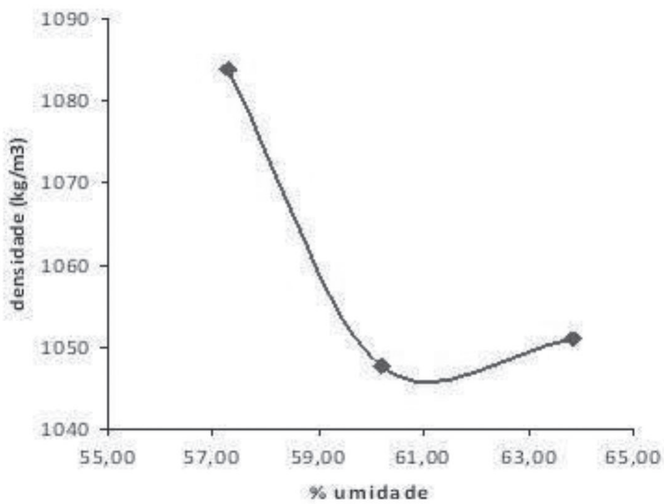

FIGURE 3 - Densit of spent coffee grounds as function of moisture content.

$$\rho_S = 7428X^2 - 5628X + 1746.2 \tag{3}$$

where ρ_s is the density and X the moisture content (w.b.).

3.2 Drying of spent coffee grounds and average particle residence time (APRT)

The experiments of drying of spent coffee grounds in the cyclonic dryer had their results presented in Table 4 and the statistical models with respect to moisture reduction, M_r, and average particle residence time, APRT, by Equations 4 and 5 with coefficients r^2 equal to 0.75 and 0.76, respectively. In those Equations, V_3 and V_4 correspond to M_r and APRT. V_1 and V_2 are related to the codified values of the ratio spent coffee grounds mass flow to air flow and temperature, respectively.

$$V3= 0.20-0.16V1+ 0.23V2 \tag{4}$$

$$V4=1.67-7.5V1 \tag{5}$$

Evaluating the statistical models in equations 3 and 4, it can be observed:

1) Higher moisture reduction (V_3) can be obtained with lower flows ratio (V_1) and higher temperature (V_2). The statistical model is in agreement with the physical behavior observed in drying processes. Increase in temperature means more energy addressed to the wet material, with consequent higher moisture transfer from the solid to the heated air (BORGES et al., 2010, 2011). Moreover, diminishing V_1 means that the quantity of the wet material is diminished with respect to the quantity of air. In such situation, the contact between air and the particles is increased, increasing moisture reduction, V_3. The increased relation between the drying agent, heated air, to the moisturized solid is reported in drying studies as the increased of the air velocity (BORGES et al., 2010) This increase causes a reduction on the external resistence to heat and mass transfer in a drying operation. These results corroborate the study of Oliveira et al. (2011) that studied the drying of sugar cane bagasse in the same experimental system.

2) The statistical model represented by Equation 4 shows that the residence time (V_4) is inversely proportional to the flows ratio (V_1), what is physically correct, and was observed in previous works using cyclone as drier, as seen in Corrêa et al. (2004a, 2004b). Diminishment of V_4 with V_1 increasing is related to decreasing of tangential velocity, which maintains the particles in a spiral movement inside the cyclone and also to an increasing of gravitational force (OLIVEIRA et al., 2011).

The results presented in Table 4 are indicative that the cyclonic dryer is an efficient dryer to particulate material as spent coffee grounds because it carries out to a great moisture reduction in a equipment that can be part of the line that transport the solid material within time in range of few seconds. Similar conclusions were obtained by Corrêa et al. (2004a, 2004b), Nebra, Silva and Mujumdar (2000) and Oliveira et al. (2011). Moreover, the cyclone is an apparatus with no moving parts where high temperatures could be used. In a industrial installation, the drying agent could be the exit gases from the boiler. Such arrangement improves the energetic efficiency of the industrial plant.

TABLE 4 - Experimental conditions and results of drying trials of spent coffee grounds using cyclonic drier, according to the experimental design

Test	V_1	V_2	V_3	V_4
1	3.1 (1)	240 (1)	3.1	0.94
2	0.6 (-1)	90 (-1)	0.6	2.33
3	3.1 (1)	90 (-1)	3.1	0.68
4	0.6 (-1)	240 (1)	0.6	5.58
5	0.1 (-1.41)	165 (0)	0.1	17.15
6	3.6 (1.41)	165 (0)	3.6	0.34
8	1.8 (0)	59 (-1.41)	1.8	1.49
7	1.8 (0)	271 (1.41)	1.8	1.44
9	1.8 (0)	165 (0)	1.8	1.76
10	1.8 (0)	165 (0)	1.8	1.63
11	1.8 (0)	165 (0)	1.8	1.61

where V_1 represents the ratio spent coffee grounds mass flow to air flow, V_2, represents the air temperature [ºC], V_3, represents the moisture variation given by (initial - final level)/ initial level, and V_4 represents the residence time of the particles.

4 CONCLUSION

The physical properties, density and granulometric distribution of the samples are dependent of the moisture content.

The statistical analysis showed that the moisture reduction of spent coffee grounds using a cyclonic dryer, in the present conditions, is inversely proportional to the solid mass flow and air mass flow ratio and directly proportional to the temperature.

The statistical model showed an inverse proportion between residence time and mass flow to air flow ratio.

The data obtained in the present work is an indicative that the cyclone is efficient for drying particulate material as spent coffee grounds because it carries out to a great moisture reduction in a equipment that can be part of the line that transport the solid material within time in range of few seconds.

5 ACKNOWLEDGMENTS

The authors want to thank FAPEMIG and FINEP for the financial support.

6 REFERENCES

ADANS, M. R.; DOUGAN, D. Waste products. In: CLARKE, R. J.; MACRAE, R. (Ed.). **Coffee: Technology.** London: Elsevier Applied Science, 1985. v. 2, p. 282-291.

BORGES, S. V. et al. Drying kinetics of banana by natural convection influence of temperature, shape, blanching and cultivar. **Ciência e Agrotecnologia**, Lavras, v. 35, n. 2, p. 368-376, mar./abr. 2011.

______. Secagem de bananas prata e d'água por convecção forçada. **Ciência e Tecnologia de Alimentos**, Campinas, v. 30, p. 605-612, 2010.

BRASIL. Ministério da Saúde. Agência Nacional de Vigilância Sanitária. **Métodos físico-químicos para análise de alimentos**. Brasília, 2005. 1018 p.

BRUN, A. A. S. et al. Métodos de extração e qualidade da fração lipídica de matérias-primas de origem vegetal e animal. **Química Nova**, São Paulo, v. 32, n. 4, p. 849-854, 2009.

BUNYAWANICHAKUL, P. et al. Numerical and experimental studies of the flow field in a cyclone dryer. **Journal of Fluids Engineering - Transactions of the ASME**, Los Alamos, v. 128, p. 1240-1250, 2006.

CENTRO DE PESQUISA EM ENERGIA ELÉTRICA. **Manual of aplicação de sistemas descentralizados de geração de energia elétrica para eletrificação rural:** energia de biomassa. Rio de Janeiro: ELETROBRÁS, 2000. 41 p.

CHU, K. W. et al. Computational study of the multiphase flow in a dense medium cyclone: effect of particle density. **Chemical Engineering Science**, Brisbane, v. 73, p. 123-139, 2012.

CORRÊA, J. L. G. et al. Cyclone as a sugar cane bagasse dryer. **Chinese Journal of Chemical Engineering**, Zhejiang, v. 12, p. 826-830, 2004a.

______. The cyclonic dryer: a numerical and experimental analysis of the geometry on average particle residence time. **Brazilian Journal of Chemical Engineering**, São Paulo, v. 21, p. 103-112, 2004b.

DEMIRBAS, A. Biofuels securing the planet's future energy needs. **Energy Conversion and Management**, Belton, v. 50, p. 2239-2249, 2009.

FOUST, A. S. **Princípios das operações unitárias**. Rio de Janeiro: LTC, 1982. 620 p.

JUNG, C. H.; PARK, H. S.; KIM, Y. P. Analytic solution to estimate overall collection efficiency and the size distribution change of polydispersed aerosol for cyclone separator. **Separation and Purification Technology,** Hong Kong, v. 68, p. 428-432, 2009.

KJELDAHL, J. A new method for the determination of nitrogen in organic matter. **Zeitschrift fur Analytische Chemie**, München, v. 22, p. 366, 1883.

KONDAMUDI, N.; MOHAPATRA, S. K.; MISRA, M. Spent coffee grounds as a versatile source of green energy. **Journal of Agricultural and Food Chemistry**, Davis, v. 56, n. 24, p. 11757-11760, 2008.

LEIFA, F.; SOCCOL, C. R.; PANDEY, A. **current developments in solid-state fermentation**. New York: Springer, 2008. 517 p.

LORA, E. S.; ANDRADE, R. V. Biomass as energy source in Brazil. **Renewable and Sustainable Energy Reviews**, Golden, v. 13, p. 777-788, 2009.

MOHSENIN, N. R. **Physical properties of plant and animal materials, structure, physical characteristics and mechanical properties**. 2nd ed. New York: Gordon and Breach Science, 1986. 103 p.

MURTHY, P. S.; NAIDU, M. M. Sustainable management of coffee industry by-products and value addition: a review. **Resources, Conservation and Recycling**, Utrecht, v. 66, p. 45-58, 2012.

MUSSATTO, S. I. et al. Production, composition, and application of coffee and its industrial residues. **Food Bioprocess Technology**, New York, v. 4, p. 661-672, 2011a.

______. Study on chemical constituents and sugars extraction from spent coffee grounds. **Carbohydrate Polymers**, Worcester, v. 83, p. 368-374, 2011b.

NEBRA, S. A.; SILVA, M. A.; MUJUMDAR, A. S. Drying in cyclones: a review. **Drying Technology,** Singapure, v. 18, p. 791-832, 2000.

OLIVEIRA, L. F. et al. Sugarcane bagasse drying in a cyclone: Influence of device geometry and operational parameters. **Drying Technology**, Singapure, v. 29, p. 946-952, 2011.

RATNADHARIYA, J. K.; CHANNIWALA, S. A. Three zone equilibrium and kinetic free modeling of biomass gasifier: a novel approach. **Renewable Energy**, Brighton, v. 34, p. 1050-1058, 2009.

RAVINDRANATH, R. et al. Composition and characteristics of Indian coffee bean, spent grounds and oil. **Journal of Science Food Agriculture**, Malden, v. 23, p. 307-310, 1972.

RIBEIRO, H. et al. From coffee industry waste materials to skin-friendly products with improved skin fat levels. **European Journal of Lipid Science and Technology**, Malden, v. 115, p. 330-336, 2013.

RODRIGUES, M. I.; IEMMA, A. F. **Planejamento de experimentos e otimização de processos**. Campinas: Cáritas, 2009. 325 p.

SANTOS, J. C. P. **Secagem de borra de café em um secador ciclônico**. 2009. 62 p. Dissertação (Mestrado em Ciência dos Alimentos) - Universidade Federal de Lavras, Lavras, 2009.

SILVA, M. A.; CORRÊA, J. L. G. Academic research on drying in Brazil 1970-2003. **Drying Technology**, Singapure, v. 23, p. 1345-1359, 2005.

SILVA, M. A et al. The use of biomass residues in the Brazilian soluble coffee industry. **Biomass and Bioenergy**, Aberdeen, v. 14, p. 457-467, 1998.

SILVA, R. et al. Applications of lignocellulosic fibers in polymer chemistry and in composites. **Química Nova**, São Paulo, v. 32, n. 3, p. 661-671, 2009.

SOCCOL, C. R.; VANDENBERGHE, R. P. S. Overview of applied solid-state fermentation in Brazil. **Biochemical Engineering Journal**, Manchester, v. 13, p. 205-218, 2003.

SOSA-ARNAO, J. H. et al. Sugar cane bagasse drying: a review. **International Sugar Journal**, London, v. 108, p. 381-392, 2006.

SOSA-ARNAO, J. H.; NEBRA, S. A. Bagasse dryer role in the energy recovery of water tube boilers. **Drying Technology**, Singapure, v. 27, p. 587-594, 2009.

VIOTTO, L. A.; MENEGALLI, F. C. Secagem de borra de café em um secador pneumático. In: ENCONTRO SOBRE ESCOAMENTOS EM MEIOS POROSOS, 20., 1992, São Carlos. **Anais...** São Carlos: UFSCar, 1992. v. 2, p. 463-479.

WERTHER, J. et al. Combustion of agricultural residues. **Progress in Energy and Combustion Science**, Pittsburgh, v. 26, p. 1-27, 2000.

XU, G. et al. Enhanced conversion of cellulosic process residue into middle caloric fuel gas with ca impregnation in fuel drying. **Energy & Fuels**, Delaware, v. 22, p. 3471-3478, 2008.

______. Gasification of coffee grounds in dual fluidized bed: performance evaluation and parametric investigation. **Energy & Fuels**, Delaware, v. 20, p. 2695-2704, 2006.

ZHANG, L.; XU, C. C.; CHAMPAGNE, P. Overview of recent advances in thermo-chemical conversion of biomass. **Energy Conversion and Management**, Belton, v. 51, p. 969-982, 2010.

ZUORRO, A.; LAVECCHIA, R. Spent coffee grounds as a valuable source of phenolic compounds and bioenergy. **Journal of Cleaner Production**, Knoxville, v. 34, p. 49-56, 2012.