EVALUATION OF COFFEE DRYING COSTS: PRE-DRYING ON CONCRETE TERRACE AND COMPLEMENTARY DRYING IN CO-CURRENT AND COUNTER-CURRENT FLOW DRYER

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ABSTRACT: The study of drying costs is an important tool to be considered when deciding on an adequate drying system. One needs to consider the energy needed for air heating, electrical energy needed to run the fans, energy to transport the product, labor costs, maintenance costs, depreciation, interest rates and breakdown costs. The objective of this study was to determine the total drying cost per bag of dry coffee beans (*Coffea arabica* L.), by drying processed coffee in the form of pulped cherries, with pre-drying on a concrete yard followed by complementary drying in a developed prototype dryer with concurrent and countercurrent flows. The dryer was constructed of a metallic frame and plates, with a static capacity of 1.55 m^3. An initial concurrent drying stage was separated from a second counter-current flow drying stage by a repose chamber. Two treatments were applied: a) Treatment 01: 12 hours of intermittent drying with intermittent rotation and 12 hours of rest, with air temperature of 45 °C and rotation of the beans every 90 minutes for drying (for a period of 10 minutes each); b) Treatment 2: 12 hours of intermittent drying with continuous rotation and 12 hours of rest, with air temperature of 70 °C. Coffee quality was determined via a sensorial analysis (cup-test). It was concluded that: The fixed cost of the multiple flow dryer was the principal component in the total cost of drying, principally since it was treated as a prototype; Increase in the drying capacity of the system with application of treatment 02 (with continuous rotation), in relation to treatment 01 (with intermittent rotation), drastically reduced total drying costs; The results obtained from treatment 01 demonstrate its economic infeasibility, due to the elevated drying costs encountered for the proposed system under the conditions in which this study was performed.

Key words: *Coffea arabica*, post-harvesting, drying costs.

1 INTRODUCTION

A cost study is an important tool to be considered when making a decision on whether or not to include a drying system for agricultural products, as well as definition of the operating mode of these systems, fuel utilized during drying and other factors. According to Silveira et al. (2008), the parameters involved in the cost of drying include: energy for air heating, energy to run the fans, energy to transport the product, labor, maintenance, depreciation, interest rates and shutdown costs.

There are diverse options for coffee drying which can include the use of concrete yards, fixed chamber dryers, cylindrical dryers and vertical dryers of crosscurrent, concurrent and countercurrent flow. However, the producer may opt for any of the drying system, taking into consideration the efficiency of the drying process and consequently the total drying cost, which act directly on the final cost of coffee production. Therefore, when adapting a drying system with a lower drying cost (and which does not compromise product quality) the total cost of coffee production can be reduced, and thus the final profit at the point of commercialization is increased.

In the search to meet the technological demands of coffee producers which contribute to more efficiently performing drying operations and without compromising quality of the commercialized product, this dryer prototype was developed. Everything was based on the physical principles of the bean drying process related to air flow and grain flow, as well as utilization of the intermediary rest chamber which aids in removal of water from the grain mass.

Coffee beans, after being processed in the form of pulped cherries, present moisture content varying from 55 to 60% (w.b.) and prior to being processed in dryers, pre-drying is necessary and is usually performed on concrete yards in order to facilitate product flow within the dryer. After drying, the product should present moisture content between 11 and 12% (w.b.) for its commercialization or storage.

In a recent study, Octaviani and Biagi (2004) determined costs for drying demucilated pulped coffee in rotating horizontal dryers, fueled by eucalyptus wood and liquefied natural gas (LPG). It was

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concluded that the cost of drying with LPG was, on average, 111.5% greater in relation to the system utilizing eucalyptus wood and that in the overall drying cost, in percent; fuel costs represented 40.76% for wood and 67.94% for LPG. Reinato et al. (2002) characterized coffee drying costs using wood and LPG as fuel for coffee cherries per-dried on concrete yards and completed in a rotary dryer, and concluded that drying costs were lower when using wood.

Santos et al. (2006) analyzed the cost of coffee drying in two rotary dryers (commercial and modified). For air heating in the commercial rotary dryer, wood was burnt in an indirect fired furnace, while in the modified rotary dryer air was heated by burning charcoal in a direct fired furnace. The total average drying costs observed in this study was R$ 12.50 per 60 kg bag of coffee. Average initial and final moisture contents observed for the treatments were 35.6 and 10.8% (w.b.), respectively.

Donzeles et al. (2007) determined costs for drying pulped cherry coffee in a yard dryer for a period of 24 hr day^{-1} while using charcoal as a fuel for air heating. Coffee was dried from an average initial moisture content of 39.6% to 12.3% (w.b.). This authors obtained a total average drying cost of R$ 35.36 for hulled coffee beans, which represents 19.2% of the average coffee commercialization price (equivalent to R$ 183.98). Both Donzeles et al. (2007) and Santos et al. (2006) utilized the methodologies cited by Silva, Pinto and Afonso (1992) and Young and Dickens (1975) and disconsidered costs of predrying performed on concrete yards.

This study considers a cost analysis of a technology for coffee drying which included the development of a concurrent and countercurrent flow dryer. The objective was to determine costs for coffee drying, processing of the pulped coffee beans, by pre-drying on a concrete yard and complementary drying in a dryer with co-current and countercurrent flows, to determine the total drying cost for hulled coffee.

2 MATERIAL AND METHODS

The product utilized was processed coffee (*Coffea arabica* L.) in the form of pulped cherries. The drying system consisted of pre-drying on a concrete yard followed by complementary drying in a dryer with co-current and countercurrent flows, developed with the intention of becoming a new drying alternative for coffee growers. The study was performed in the Experimental Area of the Department of Agricultural Engineering, Federal University of Viçosa, Viçosa – MG, in July of 2008 and economic values were updated and corrected for the harvest of 2010.

The coffee grain mass, processed in the form of pulped cherries, presented an elevated initial moisture content which complicated its flow throughout the dryers. Therefore, pre-drying was performed on concrete yards which reduced moisture content of the beans by approximately 60% w.b. to values between 40 and 25% (w.b.).

After pre-drying the coffee on a concrete terrace, the moisture content was reduced to roughly 11% (w.b.) by using the flow dryer. This dryer presents two drying stages, where in the first section the airflows are co-current and in the second the airflows are countercurrent, separated by a rest chamber which favors the migration of moisture inside the grain (Figure 1). Air movement was controlled by the suction of drying air with a centrifugal fan, and the beans were moved using a bucket elevator which carried the beans from the lower to upper portion of the dryer. Heating of the air was performed with the use of a direct fired furnace using charcoal.

Two drying experiments were performed: a) Treatment 01: 12 hours of intermittent drying with intermittent rotation and 12 hours of rest, with an air temperature of 45°C. The dryer was operated using batch loads. Rotation of the grain mass was performed every 90 minutes for a period of 10 minutes each; b) Treatment 02: 12 hours of intermittent drying with continuous rotation and 12 hours of rest, with an air temperature of 70°C. The dryer was operated using batch loads and drying was performed by more than one passage of the grains through the dryer.

In treatments 01 and 02 the air temperatures were 45ºC and 70ºC, respectively, with the intention of avoiding that the grain temperatures reached 45ºC, so as to not compromise the coffee quality in function of the elevated drying temperature. The treatments were composed of four drying tests, where for each test a control sample was dried on a suspended terrace.

The current official classification of coffee quality in Brazil is based on the Normative Instruction nº8, of June 11, 2003, which approves the Technical Regulation of Identity and Quality for Classification

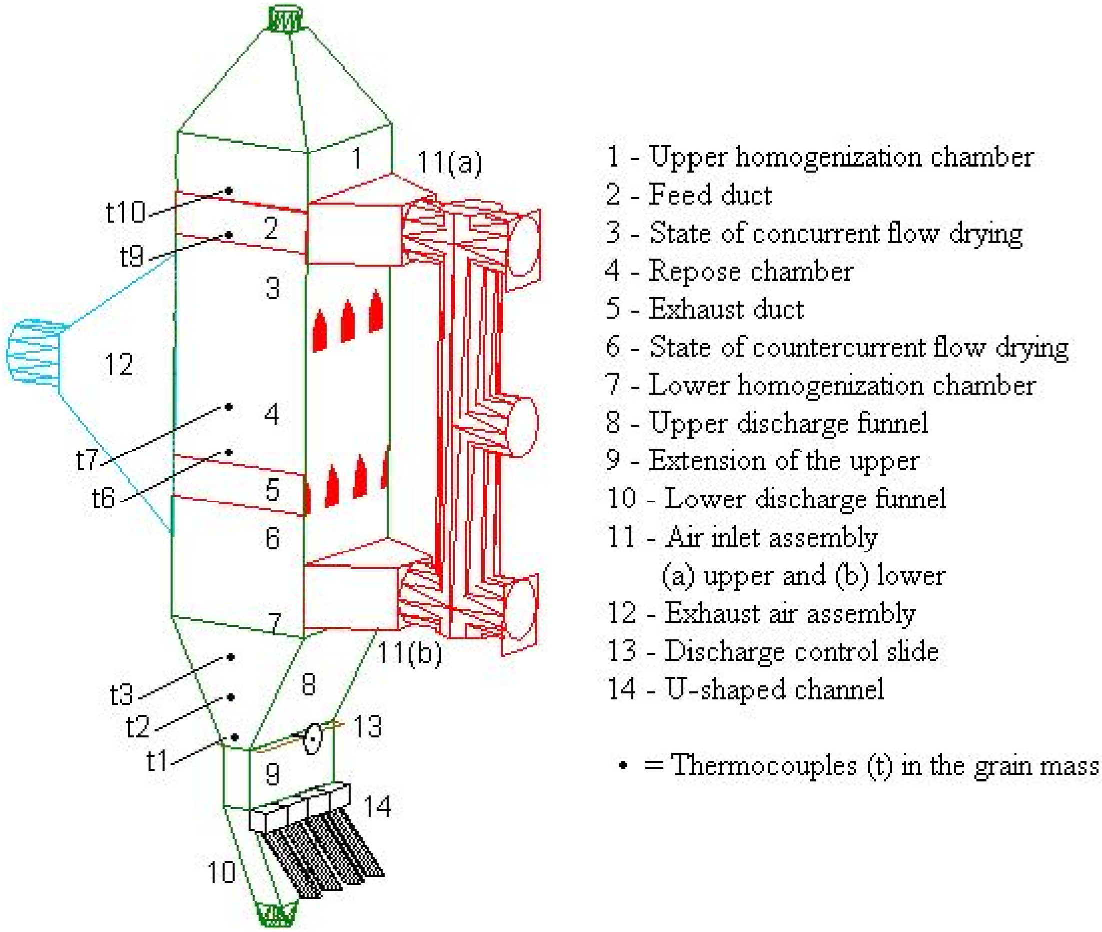

Figure 1 – Prototype of the coffee dryer

of Raw Hulled Coffee Grain. For execution of this procedure, samples were sent to a specific classifier, where the drinks were distinguished.

2.1 Cost study of coffee drying (air flow dryer)

The evaluation of drying cost (for drying occurring in the air flow dryer) was performed in accordance with the methodology described by Young and Dickens (1975). According to these authors, drying costs may be represented by summing: cost of the fuel used to heat the drying air, operational cost of the fan, operational cost of the bucket elevator and fixed cost of the system (furnace, dryer, elevator and fan), where the fixed cost includes the labor and equipment depreciation costs. Detail of each of these costs, which results in the cost of drying for the air flow dryer (expressed in R$ m^{-3} of product), is presented as follows. Initially, the fuel cost for drying (C_c) was calculated according to Equation 01 (SILVEIRA et al., 2008).

$$C_c = [m_a.(C_{pa} + RMC_{pv}).(T_{as} - T_{amb}).t_s.P_1]/[P_c.E_1.V_s] \quad (1)$$

where C_c= fuel cost for drying, R$ m^{-3} of product; m_a= mass of the air flow, kg h^{-1}; C_{pa}= specific heat of the dry air, kJ kg^{-1} $°C^{-1}$; RM= mixture ratio, kg_{vapor} $kg^{-1}_{dry\ air}$; C_{pv}= specific heat of water vapor, kJ kg^{-1} $°C^{-1}$; T_{as}= drying air temperature, ºC; T_{amb}= ambient air temperature, ºC; t_s= drying time, h; P_1= fuel cost, R$ kg^{-1}; P_c= heating value of the fuel, kJ kg^{-1}; E_1= combustion efficiency, decimal; and V_s= total volume of the product, m^3.

By means of this equation, Young and Dickens (1975) determined fuel cost in function of air mass flow, psychometric properties of the air (environment and drying), drying time, fuel costs, heating value of the fuel, combustion efficiency in the furnace and dry product volume. However, when available, the data of fuel consumption, fuel costs and dry product volume can be used to more directly obtain the fuel cost for drying (R$ m^{-3} of product), substituting data for air flow mass, psychometric properties of the air, drying time, heating value of the fuel and combustion efficiency by the consumption of fuel during the drying process.

Determination of fuel costs for drying was determined using Equation 02.

$$C_c = (C_{comb}.P_1)/V_S \quad (2)$$

Where C_{comb}= fuel consumption during the drying test, kg.

Operational cost of the fan (C_v) and the operational cost of the elevator (C_e) can be calculated in accordance with Equations 03 and 04 (SILVEIRA et al., 2008).

$$C_v = (Pot_v.t_s.P_2)/E_2 \quad (3)$$

$$C_e = (Pot_e.t_s.P_2)/E_3 \quad (4)$$

where C_v= operational cost of the fan, R$ m^{-3} of product; Pot_v= power necessary to force the air through the grain mass, kW m^{-3} of product; P_2= electricity cost, R$ kWh^{-1}; E_2= global efficiency of the fan and its motor, decimal; C_e= operational cost of the elevator, R$ m^{-3} of product; Pot_e= power necessary to lift the grain, kW m^{-3} of product; and E_3= global efficiency of the elevator and its motor, decimal.

During the drying tests, electricity consumption was obtained by direct measurement, and calculation of the operational cost of the fan and the elevator was performed by means of Equations 05 and 06. The adapted electricity cost was R$ 0.28 per kWh.

$$C_v = (C_{elev}.P_2)/V_s \quad (5)$$

$$C_e = (C_{ele}.P_2)/V_s \quad (6)$$

Where C_{elev}= energy consumption of the fan, kWh; and C_{ele}= energy consumption of the elevator, kWh.

The fixed cost of the system (C_f) was calculated by Equations 07 and 08, cited by Silveira et al. (2008).

$$C_f = [P_3 + P_4.F/t_{max}]/\min[A] \quad (7)$$

$$[A] = [(V_s/t_s) \text{ or } (V_{pmax}/t_{max})] \quad (8)$$

where C_f= fixed costs, R$ m^{-3} of product; P_3= labor costs, R$ h^{-1}; P_4= initial cost of the system (furnace, dryer, elevator, fan and installations), R$; F= costs of depreciation, maintenance, interest and fees, as a fraction of the initial equipment cost, decimal; t_{max}= maximal drying time per year, h; min[A] = lower value of V_s/t_s or V_{pmax}/t_{max} ; V_s= dryer volume, m^3; and V_{pmax}= maximal production volume per year, m^3.

Labor cost is a function of drying time (labor utilized only during the drying process for control of the dryer and refueling of the furnace). For operation of the dryer, two operators are necessary whose salary costs the employer (per operator), with all social benefits, is R$ 800.00 per month for a total of 160 working hours.

The initial cost of the system was defined by the sum of the furnace cost (R$ 3,800.00), dryer cost (R$ 5,875.00), elevator cost (R$ 6,220.00), fan cost (R$ 1,500.00) and installations costs (R$ 1,200.00).

Determination of the maximum drying time per year was performed by taking into consideration daily operation of 12 hours for a total harvest period of 75 days, totaling 900 hours per year. Equation 09 expresses the labor costs calculated in R$ h^{-1}.

$$P_3 = R_m/h_t \quad (9)$$

where R_m= monthly wages, R$; and h_t= hours worked per month, h.

In relation to depreciation and maintenance costs, interest and fees, these can be expressed as a fraction of the initial equipment cost. According to Silveira et al. (2008), this value (F) for continuous and intermittent portable dryers is 0.15, for batch silo dryers is 0.13, and for drying with natural air and slightly heated air is 0.12. Therefore, the value of F adapted in this work was 0.15; and the drying cost for the flow dryer can be represented by Equation 10.

$$C_{sec} = C_c + C_v + C_e + C_f \quad (10)$$

Where C_{sec}= drying cost in the flow dryer, R$ m^{-3} of product.

With the results obtained in R$ m^{-3} of product, these were transformed for moisture content in R$ per bag of dry pulped coffee and in function of hulling efficiency, transformed in R$ per bag of hulled coffee.

2.2 Study of pre-drying cost (concrete yard)

Considering a production capacity on the concrete yard of 50 liters per square meter, the number of days necessary for pre-drying on the yard and cost of yard construction of R$ 20 per m^2, the area necessary for pre-drying was determined as well as the initial cost of the yard.

Later, drying cost on the concrete yard was determined, considering the labor cost calculated according to Equation 09, which takes into consideration the need for one worker per 500 m^2 of yard, for an F value of 0.12.

2.3 Total drying cost

Determination of the total drying cost was performed by summing the cost of drying in the flow dryer together with the cost of pre-drying on the concrete yard.

3 RESULTS AND DISCUSSION

The results for the drying tests, with the observed energetic efficiency data (including electricity consumption), can be encountered in Tables 1 and 2.

The results for average coffee yield after hulling.

The results of the sensorial analysis can be found in Table 4.

Table 1 – Results of energetic efficiency observed in treatment 01[1]

Parameters	Test 02	Test 03	Test 04	Test 09
PREDRYING ON THE YARD				
Estimated initial moisture content, % w.b.	60	60	60	60
Days necessary for drying	7	5	6	5
DRYING IN THE AIR FLOW DRYER				
Initial moisture content, % w.b.	28.88	38.95	30.83	34.01
Final moisture content, % w.b.	12.47	11.11	11.57	11.79
Final bulk density, kg m^{-3}	419.5	422.6	418.6	403.2
Mass of the moist product, kg	717	794	744	752
Air temperature in the upper plenum, ºC	44.6	44.9	44.0	44.7
Air temperature in the lower plenum, ºC	44.3	44.7	43.6	43.8
Exhaust air flow, m^3 min^{-1}	33.3	33.9	34.3	34.7
Fuel consumption, kg	68.0	96.9	64.3	93.6
Total drying time, h	33.5	56.7	36.6	51.4
Effective drying time, h	22.0	35.0	25.2	28.6
Specific energy consumption (for the air flow dryer), kJ kg^{-1} of evaporated water				
	14,713.2	11,704.7	11,809.7	14,306.3

[1] Total drying time: refers to the time necessary for drying of the grain mass; Effective drying time: refers to the time in which the grain was submitted to the drying air, subtracting the rest periods.

Table 2 – Results of energetic efficiency observed in treatment 02[1]

Parameters	Test 05	Test 06	Test 07	Test 08
PREDRYING ON THE YARD				
Estimated initial moisture content, % w.b.	60	60	60	60
Days necessary for drying	7	6	7	7
DRYING IN THE AIR FLOW DRYER				
Initial moisture content, % w.b.	28.18	32.7	27.2	25.41
Final moisture content, % w.b.	12.65	10.56	11.45	11.55
Final bulk density, kg m^{-3}	438.6	427.3	430.5	426.9
Mass of the moist product, kg	671	754	696	661
Air temperature in the upper plenum, ºC	71.4	69.6	70.0	70.0
Air temperature in the lower plenum, ºC	71.7	69.0	69.6	69.4
Exhaust air flow, m^3 min^{-1}	33.3	33.1	33.2	33.7
Fuel consumption, kg	42.9	67.2	48.0	38.2
Total drying time, h	9.5	26.1	9.5	8.0
Effective drying time, h	9.5	14.7	9.5	8.0
Specific energy consumption (for the air flow dryer), kJ kg^{-1} of evaporated water				
	10,544.0	10,699.7	11,134.8	10,772.6

Table 3 – Average results of coffee yields.

Parameters	Treatment 01				Treatment 02			
	Test 02	Test 03	Test 04	Test 09	Test 05	Test 06	Test 07	Test 08
Coffee yield (%)	75.00	76.33	75.25	74.75	75.25	75.92	77.17	76.25
	Control 01				Control 02			
	Test 02	Test 03	Test 04	Test 09	Test 05	Test 06	Test 07	Test 08
Coffee yield (%)	74.22	75.33	74.89	73.44	71.67	72.33	72.78	73.78

Table 4 – Results of the cup-test for the treatments and controls

Treatment	Test	Drink	Control	Test	Drink
01	2	Strictly Soft	01	2	Strictly Soft
	3	Soft		3	Soft
	4	Strictly Soft		4	Strictly Soft
	9	Strictly Soft		9	Strictly Soft
02	5	Strictly Soft	02	5	Strictly Soft
	6	Soft		6	Soft
	7	Strictly Soft		7	Strictly Soft
	8	Strictly Soft		8	Strictly Soft

With regards to drink analyses performed for treatment 01 and the control, a behavior similar to that encountered in treatment 02 and control is observed, i.e., non-compromising characteristics of beverage quality in function of the drying treatments applied by the drier. Therefore, utilization of this drying system with the respective treatments can be recommended for coffee drying, requiring only a drying cost analysis to select optimal dryer management.

3.1 Evaluation of drying costs

Tables 5 and 6 present the results of the cost analysis for drying with treatments 01 and 02, respectively.

In relation to the results for total drying cost, for the average commercialization price of hulled coffee of R$ 250.00 per bag, it was observed that application of treatment 01 for the developed drying system is practically infeasible, while treatment 02 is suitable for drying demands. Drying cost represents a percentage which varies between 24.6 to 40.4% of the commercialization price of hulled coffee for treatment 01, and between 9.8 and 17.8% for treatment 02, compared to 19.2% observed by Donzeles et al. (2007).

Taking into consideration the recommendation that coffee drying in the proposed flow dryer should be constructed for a product with an initial moisture content of roughly 30% (w.b.), the results demonstrated that the drying cost for treatment 01 (with intermittent revolution) was approximately R$ 61.00 per bag of hulled coffee. However for treatment 01 (continuous revolution), the total drying cost was roughly R$ 30.00 per bag of hulled coffee. Therefore, an increase by approximately 100% in the total drying cost can be verified with the application of treatment 01 in comparison to treatment 02. On the other hand, this result can be justified in function of the

Table 5 – Drying costs referring to treatment 01

COST ANALYSIS	TREATMENT 01			
	Test 02	Test 03	Test 04	Test 09
P1 – fuel cost, R$/kg	0.5	0.5	0.5	0.5
FUEL COST FOR DRYING, R$/ bag of hulled coffee	4.69	7.02	4.42	6.65
P2 – electricity cost, R$/kWh	0.28	0.28	0.28	0.28
OPERATIONAL COST OF THE FAN, R$/ bag of dry pulped coffee	0.83	1.40	0.96	1.12
OPERATIONAL COST OF THE ELEVATOR, R$/ bag of hulled coffee	0.10	0.16	0.11	0.14
P3 – labor cost, R$/h (considering 2 operators)	10.00	10.00	10.00	10.00
P4 – initial price of the system (furnace, dryer, elevator and fan), R$	18595.0	18595.0	18595.0	18595.0
FIXED COST OF THE AIR FLOW DRYER, R$/bag of hulled coffee	39.72	66.41	45.37	53.23
DRYING COST IN THE AIR FLOW DRYER, R$/sac of hulled coffee	45.34	74.99	50.86	61.15
Volume of pulped coffee cherries harvested per day, l/day	788	460	689	609
Days necessary for predrying of coffee on the yard, days	7	5	6	5
Yard area necessary for predrying, m^2	110	46	83	61
Initial price of the concrete yard, R$	2207.5	919.7	1652.6	1218.6
Labor cost, R$/h (considering 1 worker)	5.00	5.00	5.00	5.00
COST OF DRYING ON THE CONCRETE YARD, R$/bag of hulled coffee	16.05	25.97	18.08	20.98
TOTAL DRYING COST (DRYER+ CONCRETE YARD)				
TOTAL DRYING COST, R$/bag of hulled coffee	61.40	100.96	68.94	82.13

Table 6 – Drying costs referring to treatment 02

COST ANALYSIS	TREATMENT 02			
	Test 05	Test 06	Test 07	Test 08
P1 – fuel cost, R$/kg	0.5	0.5	0.5	0.5
FUEL COST FOR DRYING, R$/ bag of hulled coffee	3.12	4.78	3.36	2.70
P2 – electricity cost, R$/kWh	0.28	0.28	0.28	0.28
OPERATIONAL COST OF THE FAN, R$/ bag of dry pulped	0.35	0.54	0.34	0.29
OPERATIONAL COST OF THE ELEVATOR, R$/ bag of hulled coffee	0.39	0.58	0.38	0.32
P3 – labor cost, R$/h (considering 2 operators)	10.00	10.00	10.00	10.00
P4 – initial price of the system (furnace, dryer, elevator and fan), R$	18595.0	18595.0	18595.0	18595.0
FIXED COST OF THE AIR FLOW DRYER, R$/bag of hulled coffee	18.11	27.41	17.40	14.79
DRYING COST IN THE AIR FLOW DRYER, R$/bag of hulled coffee	21.98	33.32	21.48	18.10
Volume of pulped coffee cherries harvested per day, l/day	1653	1127	1746	2035
Days necessary for predrying of coffee on the yard, days	7	6	7	7
Yard area necessary for predrying, m^2	231	135	244	285
Initial price of the concrete yard, R$	4629.5	2703.8	4887.5	5699.3
Labor cost, R$/h (considering 1 worker)	5.00	5.00	5.00	5.00
COST OF DRYING ON THE CONCRETE YARD, R$/bag of hulled coffee	7.77	11.22	7.51	6.50
TOTAL DRYING COST (DRYER+ CONCRETE YARD)				
TOTAL DRYING COST, R$/bag of hulled coffee	29.75	44.53	28.99	24.60

greater drying capacity of coffee per harvest, due to the fewer hours necessary to perform each drying test in treatment 02. However, utilization of a greater drying air temperature and continuous revolution contributes to a reduction of the fixed equipment cost and consequent total drying cost.

Another important observation is in respect to the fact that the drying costs were performed for daily operation of only 12 hours, in function of the applied treatments, for 75 days of harvest. Thus, in the case that the system was used for a period of 20 hours per day, which is quite common during the harvest season, drying cost may be substantially reduced.

Figure 2 illustrates the composition of drying cost in relation to the percentage of each parameter evaluated.

Composition of the total drying cost, for both treatments 01 and 02, were mostly represented by the fixed cost of the air flow dryer, followed by the second principle component which was the fixed cost of the concrete yard. For which it should be pointed out that the developed dryer refers to a prototype, and that if utilizing a dryer of greater capacity (commercial scale), the initial cost of the system would not be much different from the prototype, thus reducing the percentage of the dryer fixed cost in relation to the total drying cost. However in relation to the fuel cost for drying, Octaviani and Biagi (2004) observed average values of 40.76% and 67.94%, much greater than those observed in this study, represented by average values of 7.3 and 10.9% for treatments 01 and 02 applied.

Regarding the other costs, it can be observed that despite the encountered percentage variations between the treatments, their values correspond to a small portion of the total drying cost.

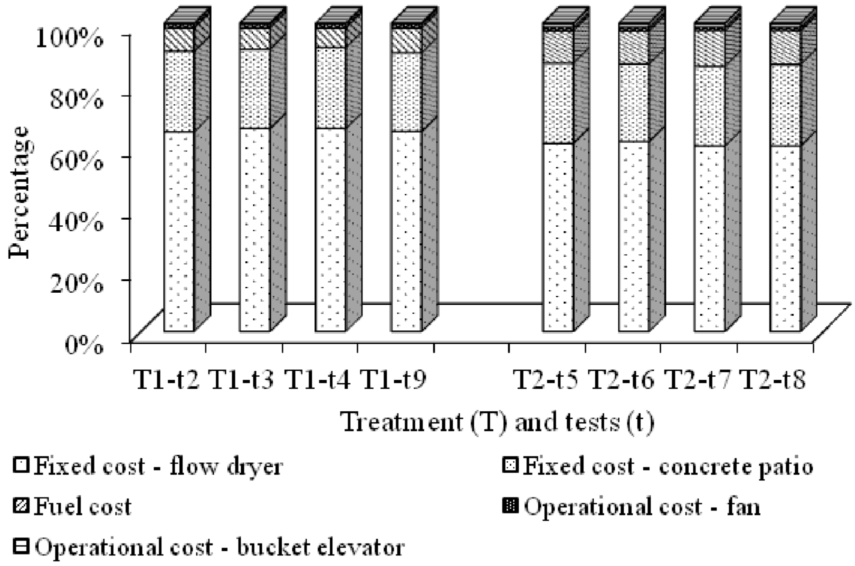

Figure 2 – Composition of drying costs in percentages (T = treatment and t = test)

4 CONCLUSIONS

The fixed cost of the air flow dryer was the principle component of the total drying cost, principally for being treated as a prototype.

Increase in the drying capacity of the system with application of treatment 02 (continuous revolution), in relation to treatment 01 (intermittent revolution), significantly reduced the fixed cost of both the flow dryer and the concrete yard, and consequently the total drying cost.

The results obtained for treatment 01 demonstrated its economic infeasibility of application, due to the elevated drying cost for the conditions under which the study was performed.

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