Development and Evaluation of Waste-Fired Dryer for Arecanut

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Abstract

Arecanut is an important component of the religious, social and cultural celebrations and economic life of people in India. Arecanut is also used in ayurvedic and veterinary medicines. About 10 % of arecanut ripens in rainy season. The high moisture in arecanut reduces its shelf-life due to development of fungal and insect attack. During rainy season, the option of drying on rooftop minimizes. A dryer has different components like drying chamber, heating unit and a chimney. The drying chamber was designed based on the quantity of arecanut to be dried, density of Arecanut and the thickness of bed. The floor-area required for drying Arecanut came as 0.92 m^2. Based on the area of the drying chamber, the trays' dimensions were finalized. Total ten trays having dimensions of 0.46 x 0.20 m were developed. Air requirement for drying was 2.56 m^3 min^{-1}. Area of drying chamber was 0.92 m^2. Whereas, heat required was 1792.6 kcal h^{-1} and the actual draft in chimney was 0.032 Pa. Based on the above assumptions, the different components of the dryer were designed.

Keywords: Arecanut, waste-fired, dryer, design, natural draft.

Introduction

India produced 7,43,220 Tonnes of Arecanut (*Areca catechu* L) from 4,45,000 ha during the year 2014-15 (Anonymous 2016). Arecanut is an important component of the religious, social and cultural celebrations and economic life of people in India. Arecanut can also be used in ayurvedic and veterinary medicines. The high moisture (71 % w.b.) in arecanut reduces its shelf-life due to development of fungal and insect attack. To avoid fungal attack and insect infestations it is spread on the rooftop of the farmer's houses for drying. The sun-drying usually takes 35 to 40 days. During rainy season, the option of drying on rooftop minimizes. The second option remains is to use mechanical hot air forced drying system. The cabinet dryer functions on electric power. The uninterrupted power supply is seldom available in rural area during rainy season. Therefore, an agro-waste-fired natural draft dryer was developed. The mature/ripened arecanuts were dried in this dryer during rainy season. The temperature inside the drying chamber found to be 60^{o}C. The waste-fired natural draft dryer is suitable to dry arecanut with capacity 15 kg per batch.

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Materials and Methods

The dryer designed based on the material need to be handled. The assumptions considered while designing the dryer are listed in Table 1. The material required for the development of the dryer MS- angles, GI-sheets, Asbestos sheets, MS-sheets and GI-pipe. The methods adopted for the development are as follows.

Design of Dryer:

A dryer has different components like drying chamber, heating unit and chimney. Based on the considered assumptions, different components of the dryer were designed. The design of drying chambers is as follows.

i) Design of drying chamber

The drying chamber designed based on the quantity of Arecanut to be dried, density of Arecanut and the thickness of bed. The floor area required for drying Arecanut was calculated as under,

$$A_d = \frac{15}{470 \times 0.035} \quad \text{.....................} \quad (i)$$

$$= 0.911 \text{ m}^2$$

$$\approx 0.92 \text{ m}^2$$

Area of drying chamber, A_d : 0.92 m^2

Where,

Mass of Arecanut, kg = 15

Thickness of bed, m = 0.035

Density of Arecanut, kg m^3 = 470

The trays' dimensions were finalized based on the area of the drying chamber. Total ten trays were designed having dimensions 0.46 x 0.20 m. Trays fabricated with the help of M.S. frame and wire mesh of size 25 x 25 mm. The space between the trays was maintained as 230 mm vertically. Accordingly the overall dimensions of the drying chamber were determined as 1.130 m (h) x 0.510 m (w) x 0.490 m (Depth). The door of drying chamber had dimensions 1.130 m (h) x 0.510 m (w). A space of 0.60 m was provided beneath the drying chamber for placing the heating unit.

The drying efficiency of the dryer depends on different factors like drying air temperature, relative humidity and flow rate.

ii) Airflow rate

The heat balance equation and psychometric chart used for finding required airflow rate. The heat loss assumed 30% of the total heat provided (Chakraverty 2000).

$$Q_a = G \times V_1 \qquad \text{...................} \qquad \text{(ii)}$$

Where,

Airflow rate, Q_a

Humid volume in air at ambient air temperature (27 °C) and at 90 % R.H. from psychometric chart, $V_1 = 0.86\ m^3\ kg^{-1}$

Rate of air supply in G, kg min^{-1}

$$G = \frac{W_1\left[(X_{id} - X_{fd})\lambda + C_{pc}(tci - t_{cf}) + C_{pw}(t_{ci} - t_{cf})X_{id}\right]}{(0.24 + 0.45H)(t_2 - t_1)\theta \times 0.70}$$

Where,

W_1 Bone-dry Arecanut = 5 kg

X_{id} Initial moisture content of Arecanut (d.b.) = 0.711

X_{fd} Final moisture content of Arecanut (d.b.) = 0.05

λ Latent heat of water vapour = 600 kcal kg^{-1}

C_{pc} Specific heat of Arecanut = 0.28 kcal kg^{-1} °C^{-1}

X_{fd} Final moisture content of Arecanut (d.b.) = 0.053

C_p Specific heat of water = 1.0 kcal kg^{-1} °C^{-1}

t_{ci} Initial temperature of Arecanut = 27 °C

t_{cf} Final temperature of Arecanut = 55 °C

H Humidity at ambient air = 0.02 kg kg^{-1}

t_2 Drying temperature of air = 65 °C

t_1 Temperature of exhaust air = 40 °C

θ Drying period of Arecanut = 30 h

Air requirement for drying, $Q_a = 2.56\ m^3\ min^{-1}$

Table 1: Assumptions for design of dryer.

Sr.No.	Parameter	Assumptions
1.	Drying temperature of air, t_2	65 °C
2.	Temperature in drying	60 °C
3.	Temperature of exhaust, t_1	40 °C
4.	Specific heat of water, Cpw	1 kcal kg^{-1} °C^{-1}
5.	Latent heat of vaporization of water	600 kcal kg^{-1}
6.	Initial moisture content of Arecanut (d.b.)	71.1 %
7.	Final moisture content of Arecanut (d.b.)	5.3 %
8.	Drying period of Arecanut, θ	30 hours
9.	Initial temperature of Areca nut, tci	27 °C
10.	Final temperature of Arecanut, tcf	55 °C
11.	Specific heat of Arecanut, Cpc	0.28 kcal kg^{-1} °C^{-1}
12.	Calorific value of Saw dust, Cn	3000 kcal kg^{-1}
13.	Weight of Arecanuts, W	15 kg
14.	Thermal efficiency	25 %
15.	Heat exchanger efficiency, ηex	35 %
16.	Combustion efficiency, η	65 %
17.	Density of Arecanut ρc	470 kg m^3

iii) Fuel requirement

The sawdust was considered as a fuel. The quantity of fuel required per hour calculated with the help of following formula.

$$F = \frac{q_a}{\eta \times \eta_{ex} \times C_n} \qquad \text{...(Chakraverty, 2000) (iii)}$$

Where,

F, Fuel rate, kg h^{-1}

q_a, Total heat required to heat the drying air, kcal h^{-1}

C_n, Calorific value of fuel = 3000 kcal kg^{-1}

η, Combustion efficiency = 0.65

η_{ex}, Heat exchanger efficiency = 0.35

$$q_a = W_1\left[(X_{id} - X_{fd})\lambda + C_{pc}(t_{ci} - t_{cf}) + C_{pw}(t_{ci} - t_{cf})X_{id}\right] \times \frac{1}{0.70}$$

= 1792.6 kcal h^{-1}

= 1.19 kg h^{-1}

The quantity of fuel required and duration of drying were the deciding factors of the dimensions of the heating unit. The overall dimensions of heating unit were 0.40 m (h) x 0.25 m (d). The air inlet of the heating unit was kept as 0.07 m.

Chimney

A chimney provided to convey the flue gases from heating unit to the atmosphere. To utilize additional heat of flue gases, the chimney passed through drying chamber. The temperature difference between outside cold air and inside hot air of the drying chamber causes pressure difference in chimney (Basunia 2001).

$$P = 0.000308 \times g \times (t_i - t_f) \times H \quad \text{.................} \quad (iv)$$

Where,

P Pressure difference between outside cold air and inside hot air, Pa

G Acceleration due to gravity = 9.81 m s^{-1}

H height of the chimney, m.

Actual draft assumed as 80% of the draft (P).

Actual draft (P_1) = 0.8 x P.

Velocity of exit air (c) = (2 x P_1/ ρe) 0.5

Volume of exit air (v_e) = quantity of air in kg ρ_e^{-1}

Rate of exit air (q_e) = v_e / drying time

Cross sectional area of chimney (a_c) = q_e c^{-1}

The pressure draft in the chimney calculated with the help of a psychometric chart and inside and outside temperature of gases.

P = 0.045 kgf cm^{-2}

From the pressure draft, the height of chimney was calculated. Therefore, from equation *(iv)* the height of chimney (H) came as 1.12 m.

The actual draft calculated as 80% of the calculated pressure draft.

P_1 = 0.80 x 0.044 = 0.032 Pa.

The velocity of exit air, C

$$C = 2 \times \frac{p_1}{\rho_a} = 0.064 \text{ m s}^{-1}$$

Volume of exit air, V_e = 0.058 m^3

Rate of exit air, q_e = 1.94 x 10^{-3} m^3 h^{-1}

Cross sectional area of chimney, a_c = 1.78 x 10-3 m^2

The temperature inside the drying chamber was found to be average 60 °C and outside temperature was 39 °C. Therefore the heat loss was 663 W.

$$Q_a = \frac{K \times A(T_i - T_o)}{X}$$ ....(Chakraverty, 2000) (v)

Where,

Q Heat loss, W

K Thermal conductivity of material, W m^{-1} °K

T_i Inside temperature of heating chamber or drying chamber, °K

T_0 Outside temperature of heating chamber or drying chamber, °K

X Thickness of material, m

A Area of heating chamber or drying chamber, m^2

Results and Discussion

The results of dryer design are as follows.

Area of drying chamber = 0.92 m^2

Air requirement for drying = 2.56 m^3 min-^{1}

Heat required = 1792.6 kcal h^{-1}

Considering Combustion efficiency as 65 % and Heat exchanger efficiency as 35 %, the actual heat available from fuel instead of 3000 kcal was about 1500 kcal h^{-1}.

Considering availability of heat 1.19 kg h^{-1} fuel was used while actual draft in chimney was 0.032 Pa.

Evaluation of the dryer

The developed dryer had two components viz. drying chamber and heating unit. The drying chamber accommodates 10 trays. The capacity of the trays was to accommodate 15 kg wet arecanuts per batch. The heating unit specially designed to get smokeless fire from agricultural waste, which last long 7 to 8 hours per filling.

The observations noted while performing drying are as shown in Table 2.

After igniting the waste in the Heating unit, it placed beneath the dryer. The air coming in contact with the heating unit become hot. This hot air tries to move upward inside the dryer. To convey the air with its natural draft, a chimney was provided. This chimney helped to create the required draft. This draft allowed the hot air to travel through chimney. The chimney provided with predetermined number of holes. These holes allow the hot air to move inside the drying chamber. The inlet of the heating unit designed in such a way that the incoming airflow is controlled which intern controls the temperature inside the drying chamber. The inlet lid was adjusted so that the average temperature in the drying chamber remains around 60 °C (Figure 1).

To get drying characteristics of arecanut, the weight of the arecanut samples recorded after every one-hour time interval. The graph in Figure 2 shows the change in moisture content of arecanut with time. The graph shows that rate of loss of moisture from the arecanut was higher initially and decreased after 20 h drying. The average time

Table 2: Observations different parameters

No.	Particular	Observations
1.	Areca nut	Initial moisture content Temperature of nuts
2.	Drying chamber.	Temperature at different locations
3.	Air	Temperature Relative humidity

Table 3: Colour of arecanut (with husk)

No.	Drying method	Colour Values		
		L	a	b
1	TRAY	25.10	4.57	9.16
2	SUN	40.324	6.974	14.128

Table 4: Colour analysis of arecanut kernel

No.	Drying method	Colour Values		
		L	a	b
1	TRAY	41.05	4.24	9.24
2	SUN	43.89	4.37	10.12

Table 5: Compression test of arecanut.

Force (KN)	
Tray dried	Sun dried
4.17	3.54

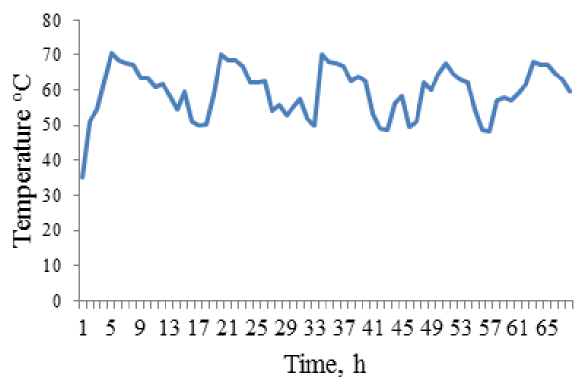

Figure 1 Temperature inside drying chamber

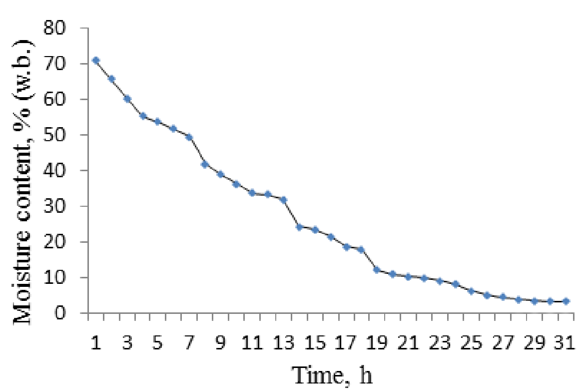

Figure 2 Moisture Content of Areca nut with time

required to reduce moisture content of arecanut from 71 % to 3.37 % was around 30 h.

The arecanut has market value based on its colour and force required to break. Therefore, a quality analysis of the dried arecanut was performed. The colour measured by the colorimeter. The Table 3 shows colour value of arecanut (With husk). The L, a & b value indicates that, the husk of tray-dried arecanut was comparatively darker than sun-dried arecanut.

Similar test was carried out on arecanut kernel (husk removed). The Table 4 shows colour of areca nut kernel. The L, a & b values were at par. It indicates that the quality of both the kernels was at par.

Figure 3. DBSKKV developed Waste-fired dryer

Abbreviations

w.b.	Wet basis
d.b.	Dry basis
MS	Mild steel
GI	Galvanized Iron
l	Lightness
a	Yellowness
b	Blueness
C.A.E.T	College of Agricultural Engineering and Technology, Dapoli

To determine the force required to break the arecanut the following test performed with the help of Universal Testing Machine (UTM). The observations recorded are listed in Table 5. Based on these results, it was observed that the tray-dried arecanuts have similar properties to those of sun-dried arecanut.

Conclusion

The temperature inside the drying chamber found to be 60 °C. The waste fired natural draft dryer is suitable to dry arecanut with capacity 15 kg per batch. The quality of the tray-dried areca nut was at par with sun dried.

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