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Design and development of a forced flow type dryer for medicinal and aromatic crops

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■ **Abstract :** Medicinal and aromatic crops like curry leaf, patchouli, senna etc. are traditionally dried under sun resulting in inferior quality produce. In order to achieve better drying in terms of quality and drying time, an attempt was made to design and develop a mechanical dryer of forced flow type based on preliminary laboratory studies on drying curry leaf. The overall dimension of the dryer was 900 x 900 x 16500 mm. The dryer consists of a drying chamber, plenum chamber, heating chamber and a blower driven by 2HP motor. The performance of the dryer was evaluated for drying curry leaves. Moisture content of curry leaves decreased from about 67 per cent to about 5 per cent (w.b.) in approximately 6 hours for drying 50 kg of fresh curry leaf. The thermal efficiency of the dryer was found to be 45.6 per cent and the heat utilisation factor was 0.32. The quality of the dried curry leaf in terms of volatile oil content, colour and rehydration ratio was found to be good.

■ **KEY WORDS :** Forced flow dryer, Design, Development, Drying, Curry leaf, Performance, Quality

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India is the largest producer of medicinal herbs and is called as botanical garden of the world (Grover *et al.*, 2002). Indian herbs are renowned all over the world for their medicinal properties. The physical and chemical properties of aromatic and medicinal plants are determined by their moisture content. Drying is one of the most critical and fundamental unit operations in the post-harvest processing of medicinal plants. The quality of drug and consequently the earnings are significantly influenced by the drying regime (Mahapatra and Nguyen, 2007). Drying involves the use of a heat source to increase the air temperature in the vicinity of the herbs to be dried. Thermal energy is used to evaporate moisture at the product surface causing a vapor pressure gradient between the product surface and interior. This gradient is what causes moisture to diffuse to the product surface. Drying also enhances the transportation and handling characteristics of herbs and spices (Shaw *et al.*, 2005). Drying process may also contribute to a regular supply and facilitate the marketing of plants, because drying results in reduction of the weight and volume of the plant with positive consequences for transport and storage (Calixto, 2000). The leaves of aromatic and medicinal plants are often dried before extraction to reduce moisture content. During this process, many compounds which are dragged to the leaf surface by the evaporating water are lost (Moyler, 1994). Traditional drying methods, such as drying in the shade or in the sun, have many drawbacks due to the inability to handle the large capacity of mechanical harvesters and to achieve the high quality standards required for medicinal plants. High ambient air temperature and relative air humidity during the harvesting season promote insect and mold development in harvested crops. Thus, traditional natural drying in the sun or in the shade does not meet the required standards or consumers demands. For this reason, adequate dryers are needed, using temperature, velocity and humidity values for drying air that provides a rapid reduction in the moisture content without affecting the quality of the active ingredients of medicinal plants (Rocha *et al.*, 2011). Mechanical dryers will be a better option for drying herbs. Care must be taken to set drying parameters such that the herbs are not exposed to excessively high temperatures, causing major losses of their medicinal, culinary, visual, and nutraceutical properties, negatively affecting the product value. Under the right conditions, drying can produce a sufficiently shelf stable product without major losses in herb value (Vinita *et al.*, 2012). If drying of the medicinal raw material is delayed, the humidity regime is favourable for the development of myco-biots, forms (Algirdas *et al.*, 2009). Under the right conditions, drying can produce a sufficiently shelf stable product without major losses in herb value (Jambor and Czosnowska, 2002). The development of new drying methods allow reaching the quality and quantity parameters (Mohammed *et al.*, 2013). Dryers are one of the most important equipment in food processing industries (Ehiem *et al.*, 2009).

Murraya koenigii (L.) Spreng of the family Rutaceae, popularly known as curry leaves is a known medicinal plant and has been used as flavouring agent in Indian food since time immemorial. Interest in greater use of this spice has been stimulated since its high antioxidant and anti carcinogenic potential were reported (Khanum *et al.*,2000) as well as the changing demographics nationwide that have created a ready market and greater demand for this spice (Palaniswamy, 2001). The leaves have good export potential besides internal consumption. Fresh curry leaves rapidly lose their moisture and get wilted. The dried curry leaves find its application as an ingredient in food and medicinal formulations.

A suitable method of drying with retention of flavour is required for export of this spice (Omanakutty *et al.*, 1984). The present system of drying this crop is under sun or shade where the quality of the end product is inferior. Based on the above background it was decided that mechanical dryer of forced flow type at high air flow and lesser temperature drying will be a better option for drying medicinal and aromatic plants. Hence, the present investigation was carried out to design and develop a forced flow type of dryer for drying medicinal and aromatic plants like curry leaf, patchouli, senna etc.

METHODOLOGY

Design of forced flow dryer for medicinal and aromatic herbage aims at: a) finding the dryer dimensions b) inlet and outlet parameters for air and materials and c) drying agent and air requirements. Some important data are known or assumed as per the need of the dryer. Clearly, no single design procedure that can apply to all or even several of the dryer variants is possible. It is, therefore, essential to revert to the fundamentals of heat, mass and momentum transfer coupled with knowledge of the material properties when attempting design of a dryer (Mujumdar and Devahastin, 2000).

Design criteria :

Based on the initial drying studies under laboratory conditions, the drying temperature and air velocity was optimized and the parameters for dryer design were arrived at.

Moisture load of dryer :

The moisture load of dryer was calculated based on capacity of the dryer and bulk density of dried curry leaf :

$$\text{Moisture load} = W_{m'} - W_m \quad \ldots (1)$$

$$\%\ \text{m.c (final)} = \frac{W_m}{W_m + W_{dm}} \times 100 \quad \ldots (2)$$

$$\%\ \text{m.c (initial)} = \frac{W_{m'}}{W_{m'} + W_{dm}} \times 100 \quad \ldots (3)$$

where, W_m-weight of moisture at final moisture content (w.b), Wm'- weight of moisture at initial moisture content (w.b), W_{dm} – weight of dry matter.

Estimated drying time :

The calculation involving the design and analysis of dryers requires the knowledge of the length of time needed to dry a product from initial moisture content to final moisture content (Ceankoplis, 1993).

$$\text{Estimated drying time} = \frac{\text{Moisture load}}{\text{Moisture removed per unit time}} \quad \ldots (4)$$

Moisture removed per unit time = Weight of drying air× amount of moisture picked up by dry air.

Dryer dimensions :

Since the geometric shape of the drying chamber is considered to be a square,

Volume of the drying chamber = a^3

Height of drying chamber = a= H_1

$$\text{Height of plenum chamber} = D_1\text{-}D_2 \tan\frac{45}{2} = H_2 \quad \ldots (5)$$

Total height of the dryer = H_1 + H_2

Volume of plenum chamber = 1/3® tan 45 $(D_1)^3 - (D_2)^3$ … (6)

where, D_1- diameter of drying chamber; D_2- diameter of plenum chamber.

Air requirement :

Heat supplied by drying air was calculated based on the following equation :

$$Qs = GS\ (t_2\text{-}t_1)^{-} \quad \ldots (7)$$

where Qs- heat supplied, kcal; G- mass flow rate of air, kg/min; S-humid heat of ambient air, kg/kg; t_1- temperature of exhaust air, ºC; t_2- temperature of heated air, ºC; θ - drying time, min.

Heat utilized :

As sensible heat of curry leaf= Bone dry weight of curry leaf ò sp. heat of curry leaf ò temperature rise …(8)

As sensible heat of water = Total weight of wateròsp. heat of water ò temp. rise … (9)

As latent heat of water vapour = water evaporated ò latent heat of water … (10)

Total heat utilized = sum of equations (8), (9) and (10)…(11)

Supposing heat loss = 10 per cent

$$\text{Net heat required} = \frac{\text{Equation (11)}}{0.90}$$

Heat supplied = Heat utilized

Air required = G×H … (12)

H- Humid volume of ambient air, m^3/kg.

Energy requirement for heating drying air :

Heating capacity of one coil = 1 KW= 14.33 kcal/min.

$$\text{Number of heating coils required} = \frac{\text{Net heat required}}{14.33 \text{ò drying time}} \quad \ldots (13)$$

Design of blower :

$$\text{Specific speed, } N_s = \frac{N \check{E} Q}{P_s^{0.75}} \quad (14)$$

N- Speed of motor, rpm

Q- air flow rate, m^3

P – static pressure, inches.

Speed :

The desired speed of rotation may be specified by the purchaser and may be based upon a standard motor speed. Since air or gas has a relatively low density the speed is higher than for pumps and may require the use of speed-up gears. In blower work standard air is generally assumed to be air at 20°C, a pressure of 1 kg/cm² absolute and a relative humidity of 36 per cent. However blowers are usually designed on the basis of a 15ºC inlet temperature and 1 kg/cm² inlet pressure and the performance curves specified for this condition. Free air is air at the pressure and temperature existing in the surrounding atmosphere. The blower is to run at 1440 rpm.

$$\text{Overall pressure ration} = \varepsilon_p = \frac{1 \text{H} 0.03}{1} \quad \ldots (15)$$

$$\frac{H}{RT0}$$

$$\frac{0.283}{= (\varepsilon_p{}^{0.283}\text{-}1)}$$

$$H\,ad = \frac{RT_a(\varepsilon_p{}^{0.283} \text{J} 1)}{0.283}$$

$$\text{Specific weight of air} : \gamma_a = \frac{P_a}{RT_a} \quad \ldots (16)$$

$$\text{Weight flow} : W_g = \frac{Q\gamma_a}{60} \quad \ldots (17)$$

$$\text{Adiabatic air horse power} = \frac{W_g H_{ad}}{75} \quad \ldots (18)$$

Inlet dimensions and vane angle :

Assuming a velocity through the impeller eye v_o of 5 m/s Velocity head,

$$H = \frac{v^2{}_0}{2g}$$

$$T_0 = \frac{T_a}{\varepsilon_p^{0.283}} \quad \dots (19)$$

The specific weight of the air in the impeller eye :

$$\gamma_0 = \frac{P_0}{RT_0} \quad \dots (20)$$

Valume flow through the impeller eye : $Q_0 = \frac{W_g}{\gamma_0}$ … (21)

The shaft diameter is based on critical speed and deflection. It will be amply strong in torsion and bending if it is made 20 cm in diameter. The hub diameter D_H, is made from 2 to 5 cm greater than the shaft diameter.

The impeller eye diameter = $D_0 = \sqrt{4\, Q_0/\pi v_0 + D^2_H}$ …(22)

The vane inlet diameter D_1 may be made slightly greater than the eye diameter;

Inlet tip speed: $u_1 = \frac{\pi D_1 n}{60}$ … (23)

The inlet velocity is assumed to be radial, *i.e.* $v_1 = v_{r1}$ and is made slightly greater than v_0

The tangent of the inlet angle: tan $_1 = v_1/u_1$ …(24)

Relative inlet velocity: $w_1 = \sqrt{u_1^2 + v_1^2}$ … (25)

In calculating the impeller areas, the flow must be increased because of leakage past the impeller. This leakage may be assumed to be about 2 ½ per cent of the flow, subject to correction after the impeller dimensions have been established.

Impeller inlet area : $A_1 = 1.025 Q_0/v_1$

Assuming a vane thickness factor e_1 of 0.85, the impeller inlet width :

$$b_1 = \frac{A_1}{\pi D_1 \varepsilon_1} \quad \dots (26)$$

Width will be checked later when the number of vanes and their thickness have been fixed.

Impeller outlet vane angle and dimensions :

$$D_2 = \frac{60\sqrt{250}}{n\sqrt{K'}} \quad \dots (27)$$

K′ is pressure co-efficient which has a value between 0.50 and 0.65, depending on the type of impeller. A value of K′ equal to 0.55 would be reasonable.

The impeller tip speed: $u_2 = \frac{\pi D_2 n}{60}$ …(28)

Number of vanes, $z = 6.5 \frac{D_2 + D_1 \sin\beta_m}{D_2 - D_2}$ … (29)

Circumferential pitch of the vanes $= \frac{\pi D_1}{z}$ … (30)

Height of the passage perpendicular to the flow is equal to circular pitch times the sine of the inlet angle.

$$vu_2 = u_2 - vr_2/\tan\beta_2$$

$$\Delta v_u = \frac{u_2 \pi \sin\beta_2}{z}$$

$$v'u_2 = vu_2 - \Delta v_u$$

$$v_2 = \sqrt{v^2 r_2 + v^2 u_2}$$

$$v'_2 = \sqrt{v^2 r_2 + v' u_2}$$

$$\tan\alpha'_2 = vr_2/v'u_2 \quad \alpha'_2 = 11^\circ$$

The virtual pressure head developed in the impeller is

$$H_{viroop} = 1/2g(u^2{}_2 - u^2{}_1 + w^2{}_1 - w^2{}_2) \quad \dots (31)$$

Performance of the dryer :

The performance of the dryer was evaluated in terms of drying efficiency and heat utilization factor of the dryer (Chakravety, 1988).

Heat utilisation factor = Heat utilized/heat supplied

. . . $_1$-TD_2/TD_1-TD ... (32)

TD = Dry bulb temperature of ambient air,°C

Thermal efficiency $= \frac{(dM/d\theta)\, W_d \lambda}{q}$ ... (33)

where,

$$q = \frac{60VA}{v}(h_1 - h_0) \quad \dots (34)$$

(dM/θ)- drying rate, kg/hr kg; Wd- weight of dry material, kg; λ - Latent heat of vaporization, kcal/kg; q - rate of heat flow, kcal/hr; V- air rate, m^3/min m^2; A- area, m^2; v- humid volume of air, m^3/kg; h_1 and h_0- enthalpy of drying and ambient air, kcal/kg.

Operation of the dryer :

The ambient air entering through the blower gets heated up in the heating chamber provided with electric heaters and enters into the plenum chamber. From the plenum chamber the hot air enters into the drying chamber where the product is kept for drying. The moisture laden air at end of drying is discharged into the atmosphere through the exhaust provided above the drying chamber. Inside the drying chamber, a pair of stainless steel stirrers has been provided for intermittent stirring which aids in quicker and uniform drying of the material.

Performance evaluation of dryer for curry leaf :

The dryer was evaluated for drying curry leaf. About 50 kg of fresh curry leaf was used for conducting trials. The curry leaves were stripped into leaflets using mechanical stripping equipment. The stripped leaves were then loaded into the dryer. With the help of temperature control unit the temperature could be set at the desired level. The air flow was found to be 8.5 m/s. The dryer was switched off when constant weight of curry leaf was achieved. The leaves were kept inside the dryer for equilibration of moisture and then packed in air tight bags. The initial and final volatile oil content was measured by hydro distillation method. The colour of the dried sample was visually observed for green colour retention. The rehydration ratio was found based on standard method (Ranganna, 1986).

■ RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Development of forced flow dryer :

Based on the preliminary observation on drying of curry leaf in a mechanical dryer, a forced flow type of dryer was designed and developed for fresh curry leaf (Fig.1). The overall dimension of the dryer was 900x900x16500 mm. The dryer consists of a drying chamber, plenum chamber, heating chamber and a blower driven by 2HP motor. The drying chamber is double walled provided with rock wool for insulation between the two walls. The heating unit is provided with electrical heaters and insulated for preventing heat loss. The plenum chamber distributes the heated air uniformly to the drying chamber where the material is kept for drying. Loading and unloading of the material is done through

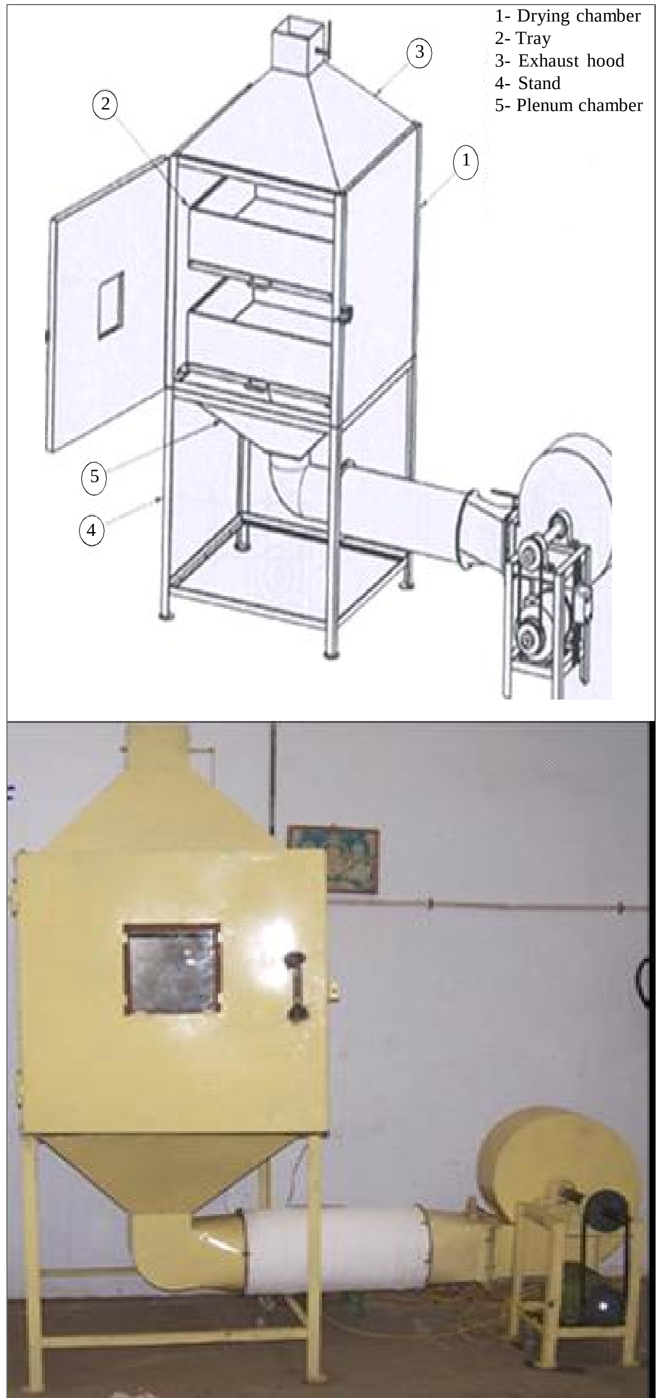

Fig. 1 : (a) Schematic diagram of the dryer (b) developed dryer

Table 1: Performance evaluation of the drier

Product	Form of drying	Moisture content, % (wb)		Vol.oil, %		Rehydration ratio	Drying time, hr	Characteristics of the final dried product
		Initial	Final	Initial	Final			
Curry leaf	Leaflet	67	5	0.6	1.65	2.6	6	Light green

the door provided at the drying chamber. An inspection door is provided at the front side of the dryer. Temperature controller is provided for regulating the temperature.

Performance of the dryer :

The performance of the dryer was calculated based on thermal efficiency and heat utilization factor. The thermal efficiency of the dryer was found to be 45.6 per cent and the heat utilisation factor was found to be 0.32

Evaluation of the dryer for drying curry leaf :

The optimum drying air temperature was found to be 45ºC based on the previous trials on drying curry leaf under laboratory condition (Dawn and Naik, 2014). About 50 kg of curry leaf was dried at 45ºC in the developed forced flow dryer. Moisture reduction in curry leaf during drying is given in Fig.2. Moisture content of the leaves decreased from about 67 per cent to about 5 per cent (w.b.) in approximately 6 hours. The performance details of the drier are presented in Table 1. It could be seen from the table that the volatile oil after drying was 1.65 per cent. The colour of the dried leaves was light green in colour based on visual observation. Rehydration ratio indicates the physical and chemical changes of the product during drying. The leaves regained their original shape once rehydrated. The rehydration ratio was 2.6 based on the initial and final weight of the samples.

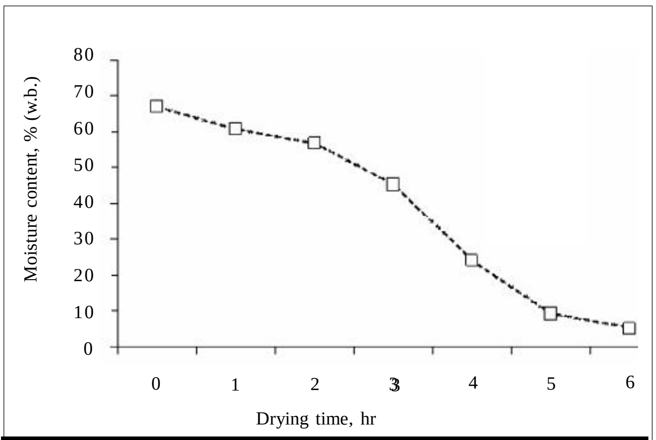

Fig. 2 : Moisture-time relationship of curry leaf during drying

Conclusion:

The developed forced flow type mechanical dryer aids in quicker drying and better quality end product. The thermal efficiency of the dryer was found to be 45.6 per cent and the heat utilisation factor was 0.32. The dryer was tested for drying curry leaf. It took 6 hours for drying 50 kg of fresh curry leaf (stripped) from an initial moisture content of 67 per cent to final moisture of 5 per cent (w.b.) The quality attributes in terms of volatile oil, rehydration ratio and colour of the dried samples was found to be good.

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