MATERIALS AND METHODS
CHAPTER III

MATERIALS AND METHODS

This chapter deals with materials and methods used for improving the engineering aspects of copra processing under the following headings.

- Copra Processing Practices Adopted and Constraints Experienced by Farmers
- Physical, Thermal and Mechanical Properties of Coconut
- Sorption Isotherms
- Development of Nut Splitting device
- Development of De-shelling machine
- Thin-Layer drying
- Deep-Bed Drying and
- Copra Dryer and quality characteristics of dried copra

3.1. Copra Processing Practices Adopted and Constraints Experienced by farmers

The research methodology adopted for the study, in accordance with the specific objectives, is presented in this section under the following sub sections.

3.1.1. Locale of the study

The study was conducted in Kerala state. Three districts, viz., Kasaragod, Ernakulam and Thiruvananthapuram representing the northern, central and southern agro-climatic zones in the state respectively, were purposively selected for the study. From each district three panchayats were randomly selected. Map showing the study area is presented in Fig.3.1.

3.1.2. Selection of respondents

The list of coconut farmers was obtained from the Krishibhavan, the panchayat level office of the Department of Agriculture, in each of the selected panchayat. From the list, 20 farmers were randomly selected from each panchayat to analyze the copra processing
Fig. 3.1. Map showing the study area of Kerala
practices adopted in their farm. Further, to study the constraints experienced in the adoption of copra dryer, 35 farmers were randomly selected from the list of coconut growers who had procured small holder’s copra dryer from the Kerala Agro Industries Corporation, Kasaragod. Thus, the total sample size was 215. The details of the respondents included for the study is furnished in Table 3.1

Table 3.1. Details of respondents included in the study

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>District</th>
<th>Panchayat selected</th>
<th>No. of farmers selected for the study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Kasaragod</td>
<td>i. Cheruvathur</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ii. Kodom-Belur</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>iii. Chemnad</td>
<td>20</td>
</tr>
<tr>
<td>2.</td>
<td>Ernakulam</td>
<td>i. Amballoor</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ii. Nedumbassery</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ii. Ezhikara</td>
<td>20</td>
</tr>
<tr>
<td>3.</td>
<td>Thiruvananthapuram</td>
<td>i. Venganoor</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ii. Karakulam</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>iii. Anacl</td>
<td>20</td>
</tr>
<tr>
<td>4.</td>
<td>Coconut farmers selected to study the adoption of copra dryer</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>215</td>
</tr>
</tbody>
</table>

3.1.3. Procedure followed for data collection

The procedure followed for data collection was given in the following sections.

3.1.3.1. Preparation of interview schedule

A draft interview schedule was prepared for collecting data from farmers taking into consideration the scope and specific objectives of the study after perusal of available literature and through consultation with experts in the field of extension education and other related fields. After incorporating their suggestions, a well structured interview schedule was constructed by including the items relating to the socio-personal characteristics of farmers and adoption of copra processing practices. Similarly, a well structured interview schedule was prepared for data collection from the selected farmers adopting small holder’s copra dryer. The interview schedules thus developed were field tested among farmers in a
non study area by the researcher. With the experience gained through field testing, the interview schedule was further refined to make the questions clearer, free from ambiguity, and to present in a simple language. The sequences of items in the interview schedule were also appropriately modified to have logical continuity in securing responses from the respondents. The final interview schedules thus prepared are famished in Annexure IA and IB.

3.1.4. Large scale processing of copra

Besides individual farmers, three large scale copra processing units situated in Kasaragod and Kannur districts of Kerala state were also included in the study and data were collected on different methods adopted for splitting, de-shelling and drying. The processing units selected were

® Kalpaka food products, Palayad industrial estate, Palayad, Kannur dist, Kerala

® The Kottachery co-operative marketing society’s coconut processing unit,
Ambalathara, Khanhangad, Kasaragod district, Kerala

® Karshaka bandhu coconut products, Kolathur, via Poinachi, Khanhangad,
Kasaragod district, Kerala

3.2. Physical, Thermal and Mechanical properties of coconut and Sorption Isotherms of copra

The materials and methods adopted for the study are reported in the following sections.

3.2.1. Physical properties

The materials and methods used to determine the physical properties of coconut such as size, shape, bulk density, true density, porosity, angle of repose, static and kinetic coefficient of friction are given in the following sub sections.

3.2.1.1. Raw material used

Fully matured (12 months old and above) West Coast Tall variety (WCT) of coconut, a local variety available abundantly in Kerala was harvested from the high density multi species cropping system plot which is more than 20 years old of Central Plantation
Crops Research Institute, Kasaragod, Kerala for all the experiments. (Unless otherwise stated, WCT coconuts were used for all the experiments). Hereafter fruit means un-husked coconuts and coconuts or nuts mean fully matured WCT de-husked and split coconuts (two halves) of 12 months and above. The fruits were de-husked manually and split into halves using a splitting device developed (reported under section 3.3.1). Shell was removed manually using a knife similar to the one being used in desiccated coconut industry for bulk density and true density studies.

The average moisture content of the freshly harvested nuts was in the range of 94.93 to 81.81 % d.b. and it was dried up to 6.0 to 6.25 % d.b. for safe storage. Ten moisture content levels were selected within this range to examine the effect of moisture content on physical and thermal properties of coconut. The samples for testing at reduced moisture contents were obtained by drying them in electrically operated hot air oven at 40 ± 2 °C and 38 - 41 % relative humidity. The desired moisture content was obtained by drying the samples using the formula given below.

\[
W_f = W_i \left( \frac{100 + M_f}{100 + M_i} \right)
\]

where,
- \( W_i \) = initial weight of the sample, kg
- \( W_f \) = final weight of the sample, kg
- \( M_i \) = initial moisture content of the sample, % d.b.
- \( M_f \) = final moisture content of the sample, % d.b.

Drying was continued for different periods to achieve the desired moisture contents in the samples. AOAC (1995) method was used to determine the moisture content of each sample.

3.2.1.2. Constituents of coconut

The characters like weight of fruit, nut, copra and shell, thickness of husk and kernel (both wet and dry), husk percentage and minimum perimeter were measured. The weights were taken on an electronic balance, AFCOSET EX-400 make having a least count of 5 g
and AFCOSET, HW-30 KA2 make having a least count of 0.001 g. The thickness was measured using vernier calipers, Mitatoys make having a least count of 0.02 mm and outside caliper, NETCO make having a least count of 1mm. The minimum perimeter was found by encircling a thread around the fruit and the length was measured using a measuring tape. The sample size was 64 coconuts.

3.2.1.3. Size

The size of the coconut was determined by taking randomly sixty four coconuts and measuring their three linear dimensions namely, length, (L) breadth, (B) and thickness (T) (breadth and thickness are almost equal) using a vernier calipers having 0.02 mm least count. The geometric mean diameter $D_p$ of fruit was calculated using the following relationship as reported by Sreenarayanan *et al.* (1985).

$$D_p = (LWT)^{1/3}$$

where,

$D_p = \text{geometric mean diameter, cm}$

3.2.1.4. Degree of sphericity

The degree of sphericity was calculated as per the equation suggested by Mohsenin (1970).

$$Sphericity = \left( \frac{\text{Volume of solid}}{\text{Volume of circumscribed sphere}} \right)^{1/3}$$

$$\varphi = \left( \frac{\pi}{6} \frac{LWT}{L^3} \right)^{1/3}$$

$$= \left( \frac{WT}{L^2} \right)^{1/3}$$

$$= \left( \frac{LWT}{L} \right)^{1/3}$$
3.2.1.5. Mass

The weight of 50 split coconut was taken on an industrial balance having least count of 5 g (AFCOSET EX-400, Japan). The mean of the mass of 50 coconuts of five replications was calculated. This is important in the design of de-shelling machine for calculating the total load on the rotating de-shelling machine.

3.2.1.6. Bulk density, true density and porosity

The bulk density of fruit, de-husked nuts, split nuts and copra, shell and husk were determined based on the volume occupied by the bulk sample by filling a box of 100 cm length, 75 cm breadth and 77 cm height with coconut. The container was then weighed and the bulk density was calculated. Ramming was not employed to avoid compaction. The procedure was repeated five times and the mean values are reported. The true density is defined as the ratio of a given mass of sample to its true volume and the same was determined by water displacement method as suggested by Shepard and Bharadwaz (1986) and Deshpande and Ali (1988). Both the densities were determined with five replications. The porosity of the bulk coconut is the ratio of the volume of internal pores in the coconut to its bulk volume and was determined by using Eqn. 3.5

\[
\varepsilon = \left(1 - \frac{p_b}{p_t}\right) \times 100 \tag{3.5}
\]

where,
- \(\varepsilon\) = porosity, %
- \(p_b\) = bulk density, kg/m³
- \(p_t\) = true density, kg/m³
3.2.1.7. Angle of repose

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined for fruit by using a hollow cylinder of 100 cm diameter and 75 cm height. The cylinder was placed at the centre of a raised circular plate having a diameter of 150 cm and was filled with coconut. The cylinder was raised slowly until it formed a cone on a circular plate. The angle of repose of split coconut and copra was determined using a hollow cylinder of 50 cm diameter and 75 cm height which was placed on a circular plate of 150 cm diameter. The height of the cone was recorded using a movable pointer fixed on a stand having a scale of 0.1 cm precision. The angle of repose was calculated using the formula.

\[ \theta = \tan^{-1} \left( \frac{2H}{D} \right) \]

where,

- \( \theta \) = angle of repose, degree
- \( H \) = height of cone, cm
- \( D \) = diameter of cone, cm

The experiment was replicated three times with different samples at different moisture content and the average was calculated.

3.2.1.8. Static and kinetic coefficients of friction

The coefficient of sliding friction is present during movement of the material and it affects the force which is exerted on the nuts and the walls of the containing vessel. The experimental set up for the determination of static and kinetic coefficients of friction of coconut was similar to the one used by Kaleemullah (1992 & 2002) in determining static and kinetic coefficients of friction of groundnut kernels and chilies respectively and Viswanathan et al. (1996a) in determining static coefficient of friction of neem nut. The experimental set up consisted of a friction less pulley fitted on a frame, a plastic hollow box of dimensions, 30 x 30 x 30 cm, loading pan and test surfaces. The box was connected by
means of a string; parallel to the test surface and passed over a frictionless pulley and a loading pan hanging from it.

The hollow plastic box was placed on the test surface and was filled with a known quantity of kernel and copra and weights were added to the loading pan until the hollow box began to slide over the test surface. The static and kinetic coefficients of friction of kernel and copra were calculated by assuming the energy loss over the frictionless pulley and the contact between hollow box and the surface material as negligible. It was also assumed that there was no rotational motion in the coconut kernel during the experiment. The static coefficient of friction was determined using the formula given below.

\[
\mu_s = \frac{F_s}{N} \quad ----3.7
\]

where,

- \( \mu_s \) = static coefficient of friction, decimal
- \( F_s \) = weight of pan and weight kept on the pan to move the box, kg
- \( N \) = weight of coconut and box, kg

The kinetic coefficient of friction was determined with the same coconut in the plastic box used in determining the static coefficient of friction. Enough weights were placed on the pan so that the box moved uniformly when a slight push was given. This was determined using the formula given below.

\[
\mu_k = \frac{F_k}{N} \quad ----3.8
\]

where,

- \( \mu_k \) = kinetic coefficient of friction, decimal
- \( F_k \) = weight of pan and weight kept on the pan to move the box with material, after giving a slight push, kg
- \( N \) = weight of coconut and box, kg

The static and kinetic coefficients of friction were determined at different moisture contents of coconut kernel and copra using different test surfaces namely, hard board, stainless steel, aluminum, galvanized iron and mild steel. For each replication, the sample of
coconut present in the hollow box was emptied and refilled with fresh sample. The experiment was replicated three times on each test surface and the average was calculated.

3.2.2. Thermal properties

The procedures adopted to determine the thermal properties such as thermal conductivity, thermal diffusivity and specific heat were explained in this section.

3.2.2.1. Raw material

The raw materials used for the determination of physical properties at various moisture content were used for the determination of thermal properties.

3.2.2.2. Thermal conductivity

The thermal conductivity of coconut was determined based on the following empirical relationship proposed by Anderson (1950) and Sweat (1974).

Anderson’s equation

\[ k = M k_w + (1 - M) k_s \]  \hspace{1cm} ----3.9

where,

\[ k = \text{thermal conductivity of unknown material, W/m K} \]

\[ k_w = \text{thermal conductivity of water, 0.614 W/m K} \]

\[ k_s = \text{thermal conductivity of solids, 0.2597 W/m K} \]

\[ M = \text{moisture content of material, w.b.} \]

Sweat’s equation

\[ k = 0.00493M + 0.148 \]  \hspace{1cm} ----3.10

where,

\[ k = \text{thermal conductivity of unknown material, W/m K} \]

\[ m = \text{moisture content of material, w.b.} \]

3.2.2.3. Thermal diffusivity

The thermal diffusivity of coconut was determined by using the relation given below.

\[ \alpha = \frac{k}{\rho_s C_p} \]  \hspace{1cm} ----3.11

where,

\[ \alpha = \text{thermal diffusivity of coconut, m}^2/\text{s} \]
3.2.3. Mechanical properties

The procedures adopted to determine the mechanical properties such as surface area, shell thickness and calorific values of shell and husk were explained in this section.

3.2.3.1. Surface area

The surface area of kernel was determined without splitting the coconut into halves i.e. the shell was removed carefully by a splitting tool which is commonly being used in the desiccated coconut industry. The shape of the tool is like a small axe made of carbon steel with a wooden handle. The ball shaped kernel was cut into different sizes. Weight surface area relationship is needed while computing water loss and absorption. The surface area

\[ C_p = \text{specific heat of coconut, } J/\text{kg} \cdot \text{K} \]
\[ k = \text{thermal conductivity of coconut, } W/\text{m} \cdot \text{K} \]
\[ \rho_b = \text{bulk density of coconut, } \text{kg/m}^3 \]

3.2.4. Specific heat

The specific heat of coconut was calculated using the equation proposed by Charm (1971) and Heldman (1975).

Charm equation

\[ C_p = 2093 X_f + 1256 X_s + 4187 X_m \] ----3.12

Heldman equation

\[ C_p = 1424 X_c + 1549 X_p + 1675 X_f + 837 X_s + 4187 X_m \] ----3.13

were,

\[ C_p = \text{specific heat of a food product, } J/\text{kg} \cdot \text{K} \]
\[ X_f = \text{mass fraction of fat, decimal} \]
\[ X_s = \text{mass fraction of solid, decimal} \]
\[ X_m = \text{mass fraction of moisture, decimal} \]
\[ X_c = \text{mass fraction of carbohydrate, decimal} \]
\[ X_p = \text{mass fraction of protein, decimal} \]
\[ X_a = \text{mass fraction of ash, decimal} \]

The mass fraction reported by Mathew (1991) for West Coast Tall variety of coconut was used for determining the specific heat at various moisture contents.

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\[ C_p = \text{specific heat of coconut, } J/\text{kg} \cdot \text{K} \]
\[ k = \text{thermal conductivity of coconut, } W/\text{m} \cdot \text{K} \]
\[ \rho_b = \text{bulk density of coconut, } \text{kg/m}^3 \]
predicted is also required for heat treatment studies (Baten and Marshall, 1953). Coconut kernel was cut into square pieces and the size and weight were recorded. The surface area of the kernel was determined by tracing the cut slices of coconut on a graph sheet. Similar method was followed for apple by Baten and Marshall (1953) and Frechetta et al. (1966). The surface area of the fruit was found by analog with a sphere of geometric mean diameter by using the relationship given by McCabe et al. (1986)

\[ s = \pi D_p^2 \]

where,

- \( s \) = surface area, cm

- \( D_p \) = geometric mean diameter, cm

### 3.2.3.2. Shell thickness

Coconuts were randomly selected and the thickness opposite to each eyes were measured using vernier calipers with least count of 0.02 mm, to study the variation in thickness and to assess the fracture zone. The sample size was 200 nuts. The eyes were named as larger eye (germinating eye) and other two eyes which are adjacent to each other.

### 3.2.3.3. Splitting Force

The splitting force was found by using a pendulum impact test apparatus. The schematic representation of pendulum test apparatus is given in Fig. 3.2. A cutting knife was attached to the end of the pendulum arm and this arm was released from various heights by using a spring loaded lock. Pointers were provided on the axis of rotation of the pendulum arm, to indicate the angular displacement on a scale graduated in degrees. To obtain different cutting velocities of the knife, the pendulum arm was released from different height. The radius of the pendulum arm was 0.9 m and the total weight was 2.4 kg.

Knife bevel angles of 15, 20, 25, 30, and 35° were used in the study to find the best angle of the knife for the splitting device. One sided bevel was used as shown in the Fig. 3.2. The coconut was held between two oversized pipes having a small opening for the impact force of the pendulum. Immediately after splitting, the nuts slipped into the pipes
there by allowing the pendulum to move on the upward side (up swing). As the size of coconut varies, the cutting force was calculated on the basis of the average values for five coconuts for each bevel angle.

3.2.3.3.1. Theoretical considerations

When the pendulum arm is in equilibrium (Fig.3.2) position, the potential energy stored is zero. But when the pendulum arm is at a position making an angle ‘\( \theta_i \)’ with the equilibrium position, the potential energy stored will be

\[
E_i = WR \left( 1 - \cos \theta_i \right)
\]

---3.15

If the arm is released from the initial position \( \theta_i \) and moved to \( \theta_o \) degrees on the other side from the vertical position in the absence of splitting, then the energy loss \( E_f \) due to friction and air resistance will be

\[
E_f = WR \left[ (1 - \cos \theta_i) - (1 - \cos \theta_o) \right]
\]

---3.16

\[
= WR \cos (\theta_o - \theta_i)
\]

---3.17

When the impact tool is attached to the pendulum arm, the tool will split the coconut and advance during its swing with deceleration. If ‘\( \theta_c \)’ is the angular displacement of the pendulum arm in the upswing after impact and splitting the coconut, then the energy absorbed in the impact process is given as

\[
E_c = E_i - E_f - E_o
\]

---3.18

Substituting the values of \( E_o, E_f \) and \( E_o \) in eqn. 3.18 we get

\[
E_c = WR \left[ (1 - \cos \theta) - (\cos \theta_o - \cos \theta_i) - (1 - \cos \theta_c) \right]
\]

---3.19

But \( E_c = FL \theta_c \)

\[
F = \frac{WR (\cos \theta_c - \cos \theta_o)}{L \theta_c}
\]

---3.20

\[
F = \frac{WR}{L \theta_c}
\]

---3.21

\[
The mean stress was calculated by
\]

\[
Stress = \frac{F}{A}
\]

---3.22

---3.23
Fig. 3.2. Schematic representation of Pendulum impact test apparatus
3.2.3. Calorific value of shell and husk

The calorific value of shell and husk was determined using the Advance Isothermal Bomb calorimeter as per methods recommended by Bureau of Indian Standards (IS: 1359-1959).

The calorific value of shell and husk were determined for coconut having different maturity of nuts. Coconuts of immature (less than 10 months), mature (11 months and above) and fully mature (12 months and above) were harvested and shell and husk were separated and dried in hot air oven at 40 ± 2 °C till it gave constant weight. The powder form of shell and husk was obtained by grinding on a power operated grinding machine. The powder was then sieved using IS sieve 20 (211 microns).

3.2.4. Sorption Isotherms

The materials and methods used to determine the sorption isotherms of copra were given in this section.

3.2.4.1. Experimental procedure

Equilibrium moisture content was determined both in desorption and adsorption conditions at three temperature levels (25, 35 and 45 °C) and eight relative humidity levels.
(11 to 87 %) using static method. Various super saturated salt solutions were used to provide constant relative humidity at different temperatures (Table. 3.2).

Preliminary experiments were conducted to determine the range of expected values of equilibrium moisture content by storing the samples of partially dried copra in the environment corresponding to 45 °C and 11 % RH and 25 °C and 86 % RH for a period of 30 days. The equilibrium moisture content was in the range of 2.5 to 15 % d.b. Hence the samples for adsorption and desorption had to be pre conditioned. The samples were conditioned to 20 % d.b for desorption purpose and 2 % d.b. for adsorption. The samples were conditioned by drying the samples in hot air oven at 40 ± 2 °C till the desired moisture contents were obtained (AOAC, 1995).

Glass desiccators containing about 400 ml of saturated salt solutions were used to provide constant RH varying from 11 to 87 %. The desiccators were placed inside a hot air oven with thermostat control and specified temperatures were maintained.

Samples of pre-conditioned copra (10 g each for desorption and 5 g each for adsorption) were placed in Petri dishes and these dishes were placed on a plastic platform inside the desiccators to avoid direct contact between copra and salt solution. After 30 days period, the Petri dishes were removed from controlled atmosphere space and stored in activated silica gel for 3 h to allow them to attain room temperature (Verma and Gupta, 1988). All the experiments were replicated three times and the average of the three values was used in the analysis.

3.3. Nut Splitting Device

The design and fabrication of the splitting device and experimental procedure used for splitting were explained in the following sections.

3.3.1. Development of a manually operated nut splitting device

A manually operated splitting device was designed and fabricated to study the performance in comparison with the traditional practice of splitting coconut using a
Table 3.2. Relative humidity of saturated salt solutions at different temperatures

<table>
<thead>
<tr>
<th>Salt</th>
<th>Temp. °C</th>
<th>RH, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiClH₂O</td>
<td>0.0</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>20.0</td>
<td>12.4</td>
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<tr>
<td></td>
<td>30.0</td>
<td>11.8</td>
</tr>
<tr>
<td></td>
<td>40.0</td>
<td>11.6</td>
</tr>
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<td></td>
<td>50.0</td>
<td>11.4</td>
</tr>
<tr>
<td>KC₂H₃O₂</td>
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<td>23.2</td>
</tr>
<tr>
<td></td>
<td>25.0</td>
<td>22.7</td>
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<tr>
<td></td>
<td>30.0</td>
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<tr>
<td></td>
<td>37.8</td>
<td>20.4</td>
</tr>
<tr>
<td>MgCl₂·6H₂O</td>
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<td>35.0</td>
</tr>
<tr>
<td></td>
<td>20.0</td>
<td>33.6</td>
</tr>
<tr>
<td></td>
<td>30.0</td>
<td>32.8</td>
</tr>
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<td></td>
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<td>32.1</td>
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<td></td>
<td>50.0</td>
<td>31.4</td>
</tr>
<tr>
<td>K₂CO₃</td>
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<td>74.5</td>
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<tr>
<td>(NH₄)₂S₀₄</td>
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<td>83.7</td>
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<td>K₂CrO₄</td>
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<td>86.6</td>
</tr>
<tr>
<td></td>
<td>25.0</td>
<td>86.5</td>
</tr>
<tr>
<td></td>
<td>30.0</td>
<td>86.3</td>
</tr>
<tr>
<td></td>
<td>37.8</td>
<td>85.6</td>
</tr>
<tr>
<td>K₂SO₄</td>
<td>0.0</td>
<td>99.1</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>97.9</td>
</tr>
<tr>
<td></td>
<td>20.0</td>
<td>97.2</td>
</tr>
<tr>
<td></td>
<td>30.0</td>
<td>96.6</td>
</tr>
<tr>
<td></td>
<td>40.0</td>
<td>96.2</td>
</tr>
<tr>
<td></td>
<td>50.0</td>
<td>95.8</td>
</tr>
</tbody>
</table>

(Source: Hall, 1970)
traditional knife. The materials and methods used to fabricate the primary components of a functionally effective splitting device such as the nut holder, knife bevel angle; nut water collection trap and main frame are given below. The splitting device developed is shown in Plates 3.1, 3.2 and 3.3.

3.3.1.1. Main frame

The main frame was fabricated using angle iron bar of size 50 x 50 x 6 mm. The material required along with the cost of each component is given in Appendix - II.

3.3.1.2. Method of fabrication

The fabrication of the device was done as shown in the Fig. 4.21. In order to make the supporting stand of the splitting platform angle iron bars of 50 x 50 x 6 mm size were welded to get the rectangular base frame of 50 x 40 cm. The 50 mm I D “B” class pipe of 95 cm length was welded vertically to the base frame at one end. Above the M.S.pipe two pieces of 40 x 40 x 6 mm angle iron of 30 cm length were welded vertically with 12 mm holes to fix the splitting tool frame. Additional holes were provided for adjustment of the cutting tool. A support box frame made of 25 x 25 x 3 mm, M.S. angle and 16 guage, M.S. sheet was welded to the vertical pipe at one end and the other and was supported with 15 mm M.S. rod with the base platform. Above the support box frame M.S. nut holder was provided to hold the split nut. The nut support box frame was given an inclination of 45° towards the bottom base, so that the coconut water will flow through the inclined surface into the channels provided all along the base of the box. HSS splitting tool was fixed on the handle provided as shown in Plate 3.1. The design drawing is shown in Fig. 4.21.

The round frames to hold the basket was made of 12 mm M.S. rod, welded on both sides of the main frame for holding split nuts. Provision was also made to drain the coconut water and to collect at the bottom using pipe.
Plate 3.1. View of coconut splitting device

Plate 3.2. Nut holder with knife and rubber bush
Plate 3.3. Testing of coconut splitting device
3.3.1.3. Nut holder

Nut holder of the splitting device was fixed based on the average diameter of 200 coconuts. The length and diameter was recorded and was analyzed to get the mean values. The mean diameter was 9.41 cm. Thus the nut holder’s diameter was fixed at upper level of 9.5 cm to accommodate all sizes of nuts. This was made using hard but flexible rubber which was pasted on a mild steel disc (Plate 3.2) of 9.5 cm using araldite (an adhesive). At the center of the nut holder a sharp and curved knife was welded. The splitting knife and the knife of the nut holder lie in the same vertical plane.

3.3.2. Knife bevel angle

Various knife bevel angles like 15, 20, 25, 30, and 35° were fabricated and used for splitting the nuts. The material used for the fabrication of knife was high speed steel. Knife bevel angles were made by grinding the material on a power operated grinding machine. Provision was made on the knife holder for easy replacement of knife with different bevel angles using bolts and nuts.

3.3.3. Performance evaluation

The performance was evaluated based on splitting trials conducted with optimized knife angle and was compared with traditional method of splitting followed by fanners and processing units.

3.3.4. Cost economics

Based on the materials used and the fabrication charges of the splitting device, the cost of the unit was calculated. The cost of splitting of coconut was worked out using the standard procedure (Appendix - V).

3.4. De-Shelling Machine

The design of de-shelling machine and procedure followed during de-shelling were explained in the following sub sections.
3.4.1. Development of de-shelling machine

A batch type de-shelling machine was designed and fabricated to hold 200 split coconuts. The materials and methods used to fabricate the primary components of a functionally effective de-shelling machine such as de-shelling chamber, main frame motor and reduction gear box are given in the following sections. The de-shelling machine designed is shown in Plate 3.4.

3.4.1.1. De-shelling chamber

De-shelling takes place due to the impact force caused by the fall of split and partially dried coconuts one over the other. The maximum capacity of the chamber was assumed to be 200 split nuts. By assuming the length of the deshelling chamber, the radius of the cylindrical chamber was determined by using the following formula.

\[ r = \frac{4m}{3 \times p_b \times \pi \times L} \]  

---3.24

where,

\[ r = \text{radius of de-shelling chamber, m} \]
\[ L = \text{length of the de-shelling machine, m} \]
\[ m = \text{weight of 200 split nuts at a moisture content of 34 % d.b., kg} \]
\[ p_b = \text{bulk density of split coconut at moisture content of 34 % d.b., kg/m}^3 \]

3.4.1.2. Flights

As the coconuts have to be carried from bottom to top of the de-shelling chamber, flights were incorporated in the design. The depth and width of the flights were calculated by using the following formula.

\[ D = 0.6472 r \text{ (Appendix-VIII)} \]  

---3.25

\[ W = 0.75 D \]  

---3.26

Where,

\[ W = \text{width of flight, cm} \]
\[ L = \text{length of flight, cm} \]
\[ D = \text{depth of the flight, cm} \]
Plate 3.4. Overall view of the coconut de-shelling machine
3.4.1.3. Motor

The following formula was used to calculate the horsepower of the motor which was necessary to rotate the de-shelling chamber.

\[ h_p = \frac{2\pi NT}{4500\eta_m} \]  

---3.27

Where,

- \( h_p \) = horse power of motor required
- \( N \) = number of revolutions /minute
- \( T \) = torque, kg-m
- \( \eta_m \) = motor efficiency, %

3.4.1.4. Reduction gear box

A reduction gear box having a speed ratio of 144:1 (Make: Cyclo, Bangalore) was used in conjunction with a motor and a set of pulleys to rotate the deshelling chamber at different speeds.

3.4.1.5. Fabrication of major components

The method of fabrication of major components is given in the following sub-sections. The design drawing is shown in Fig. 4.22

3.4.1.6. Main axle

The main axle was fabricated using 60 mm OD mild steel shaft of 1.75 m length by suitably reducing the ends to accommodate bearings (2 no) and one pulley. Provision was also made on the shaft to insert a key to secure the pulley in position tightly. The size of the bush used was 50 mm (ID) x 90 mm (OD) x 75 mm (L).

3.4.1.7. De-shelling chamber

The circular de-shelling chamber was fabricated using seamless pipe of 283 cm length and 25 mm (ID). The diameter of the de-shelling chamber was 90 cm. Two numbers of identical circular pipes were used. These two circular pipes were connected using 40 numbers of 25 x 25 x 6 mm ‘T’ angles with a gap of 25 mm in between them. The
‘T’ angles were welded in such a way that the projected ‘T’ was facing inside. Flights were provided as given in section 3.4.1.2. A door was provided with facility to open for easy loading and unloading. The sides of the chamber were connected to the main axle with the help of 6 numbers (3 on each side) 100 x 10 x 320 mm mild steel plate. The sides of the chamber were closed using 25 x 25 x 10 gauge weld mesh as shown in Plate 3.4.

3.4.1.8. Main support frame

The rectangular supporting frame on which the main axle along with the de-shelling chamber rests was fabricated using 75 x 75 x 8 mm size mild steel angle iron as main support frame which was connected with 50 x 50 x 6 mm mild steel angles along all the sides. The height of the support frame was 110 cm and width 144 cm. The bearing housing was fixed on the support frame and the entire unit was fixed as shown in Fig. 4.22 and Plate 3.3. The motor and reduction gear box were mounted separately using suitable frame work. Both the frames were fixed on the ground using suitable bolts and nuts to avoid vibration.

3.4.2. Experiment

Experiment was conducted to optimize the speed of the de-shelling chamber and moisture content of copra for maximum de-shelling efficiency.

3.4.3. Cost economics

Based on the materials used and the fabrication charges of the de-shelling machine, the cost of the unit was calculated. The cost of de-shelling was worked out using the standard procedure (Appendix - VI).

3.5. Thin-Layer Drying

The details of thin-layer dryer and the procedures used to determine quality characteristics are discussed. The models used for fitting thin-layer drying data were also given in this section.
A laboratory model dryer was developed for the study. This mainly consists of a motor-blower assembly, heating chamber, plenum chamber, drying chamber, sample container and a thermostat as shown in Fig. 3.3. A centrifugal blower of 1.5 m$^3$/min. capacity was used to blow the drying air. It was connected with a 0.5 hp electric motor. Manually operated control valve was provided to regulate the air flow through the system at the desired level. The air heating system located between the blower and the plenum chamber, consisted of two heating elements of 1.0 kW each.

A thermostat was fixed in the plenum chamber so as to control the temperature of incoming hot air into the drying chamber with an accuracy of ± 2 °C. A mild steel sample container, 340 mm diameter and 200 mm depth, with a 5 mm hole size screen bottom were placed on top of the plenum chamber.

3.5.1.1. Experiment

Before conducting any experiment, the experimental set up was allowed to run for 10 minutes till the desired drying temperature attained a steady state condition. The ambient inlet and exhaust hot air temperatures were recorded using electronic automatic temperature recorder, (Tempsen make, Asian Engineering and services, Chennai, India) having a range of 0 to 1000 °C. The moisture content of the sample for drying tests was determined using the copra moisture meter developed by Madhavan (1985) which is commercially manufactured and marketed by Kerala Agro Industries Corporation Limited, Kasaragod, model CMM: KP 21 V9. The accuracy of the moisture meter was compared with AOAC (1995) and the moisture readings were found to have an accuracy of ± 0.5 % w.b. The relative humidity was measured using Barigos hygrometer. After finishing the experiment, one halt nut was once again dried in the experimental environmental condition till it gives a constant weight. This sample was used to determine the equilibrium moisture content of the sample in the experimental environmental condition.
Fig. 3.3. Thin-layer dryer

1. Motor
2. Step pulley
3. Blower
4. Heating coil drum
5. Drying chamber
6. Step heater
7. Thermostat
3.5.2. Effect of drying air temperature on drying time and quality characteristics of copra and oil

The first experiment was carried out to determine the effect of drying air temperature on drying characteristics of coconut and to optimize the drying temperature based on drying time, colour, taste, smell, free fatty acid content, peroxide value, acid value, fungal growth and oil content of copra. The oil analysis, free fatty acid, peroxide value and acid value were determined as per Sadasivam and Manickam (1992). Organoleptic evaluation of copra was done by a panel of 10 judges who are actually involved in the copra processing business for colour, taste, smell, and by visual observation for fungal growth. Thin layer drying experiments were conducted at 50, 60, 70, 80, 90 and 100 °C hot air temperatures. Each experiment was replicated three times and the average values were used for analysis. Four coconuts were taken and its initial moisture content was noted. The nuts were kept in the drying chamber in single layer. The split coconut halves were placed in the drying chamber with kernel portion facing the direction of air flow. Drying was carried out with constant air flow rate of 0.5 m/s, the recommended air velocity for industrial drying of coconut (Nampoothiri et al, 1986). All the experiments were conducted in the prevailing atmospheric conditions. Form each coconut five moisture content readings were taken and the average was used for all calculations. Removing, taking moisture reading and replacing of the samples took about two minutes.

3.5.3. Effect of drying air temperature on quality of copra

As the temperature affects the quality of coconut, the temperature of hot air was optimized based on the nine-point scale (on par with nine-point hedonic scale and ISI specification: IS 6273-1971) given to drying time, colour, taste, smell, free fatty content, fungal growth and oil content of copra. The nine-point scale range was fixed based on IS 6273-1971, those reported in literature and thin-layer drying experimental maximum and minimum values of the drying time, colour, taste, smell, free fatty acid content, fungal growth and percent oil content of copra (Table 3.3).
3.3. Nine point scales to classify the drying time, smell, taste, colour, oil content
and free fatty acid for coconut dried in thin layer dryer

<table>
<thead>
<tr>
<th>lg n</th>
<th>Smell</th>
<th>Taste</th>
<th>Colour</th>
<th>Fungal growth</th>
<th>Oil content, %, d.b</th>
<th>Free fatty acid, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>(9)</td>
<td>Typical (9)</td>
<td>Typical (9)</td>
<td>White (9)</td>
<td>Hot visible (8)</td>
<td>65-70 (9)</td>
<td>~0.1 (9)</td>
</tr>
<tr>
<td>(7)</td>
<td>Slightly burnt (7)</td>
<td>Slightly burnt Light Brown (7)</td>
<td>Traces (7)</td>
<td>60-64 (7)</td>
<td>0.1-0.2 (7)</td>
<td></td>
</tr>
<tr>
<td>(5)</td>
<td>Burnt (5)</td>
<td>Burnt (5)</td>
<td>Deep brown (5)</td>
<td>Visible (5)</td>
<td>55.59 (5)</td>
<td>0.21-0.29</td>
</tr>
<tr>
<td>(3)</td>
<td>Slightly charred (3)</td>
<td>Slightly Brown (3)</td>
<td>Fully affected</td>
<td>50.54 (3)</td>
<td>0.30-0.34</td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>Charred (1)</td>
<td>Charred (1)</td>
<td>Black (1)</td>
<td>Spoiled (1)</td>
<td>&lt;49 (1)</td>
<td>&gt;0.35 (1)</td>
</tr>
</tbody>
</table>

* Parenthesis indicate scores

Score was given to all the coconuts dried at 50, 60, 70, 80, 90 and 100 °C hot air

effect of temperature on fatty acid composition of coconut oil

Coconut samples were dried at different temperatures to assess the influence of
temperature on oil output and fatty acid composition of oil. Coconuts were dried at
air temperatures ranging from 40 to 110 °C with 10 °C interval. Thus a total of 8
its were carried out. In all the treatments, copra was dried to 6.25 % moisture
dry basis). Oil was extracted from copra samples using Soxhlet apparatus. In this
extraction method, known amount of copra was crushed in mortar and pestle by
equal amount of sodium sulphate. Petroleum ether was used as a solvent. The oil
in copra was determined by gravimetric method.

The fatty acid profile was analyzed after methyl esterifying the oil samples using
reagent (Pauda and Benzon, 1979 and Maresh et al, 2000). The esterified samples
cled into the Gas Chromatograph (GC 2010 with auto injector, Shimadzu, Japan)
with capillary column. The retention times of samples were compared with that of
methyl ester standards to identify the specific fatty acids.

effect of drying air velocity and temperature and air velocity on drying time of

cpra

The second experiment was carried out to study effect of drying air velocity viz., 1
m / s at 50, 60, 70, 80, 90 and 100 °C hot air temperatures on drying characteristics
of coconut. Each experiment was replicated three times and the average values were used for analysis.

3.5.6. Drying characteristics of copra in hot air oven

The third experiment was carried out to see the drying characteristics of coconut in hot air oven. The hot air electric oven, make BAGSVIG, single phase with 3 kW heaters and maximum temperature of 150 °C was used to conduct the experiment. Coconut was kept in the oven in single layer at 50, 60, 70, 80, 90 and 100 °C hot air temperatures. Each experiment was replicated three times and the average values were used for analysis.

3.5.7. Models

Three thin-layer drying models (Lewis, Hustrulid & Flikke and Page) mentioned in section 2.5.1 were selected for fitting the experimental data of thin-layer drying of coconut at 50, 60, 70, 80, 90 and 100 °C at air velocity of 0.5 m/s. Many models were tried which is presented in Tables 4.35 and 4.37. The proposed models (3.28, 3.29, and 3.30) were compared with the selected three thin-layer drying models.

(i) \[ MR = b_0 + b_1 x + b_2 x^2 + b_3 x^3 \] ---- 3.28

(ii) \[ MR = A \exp (-kx) + B \exp (-lx) \] ----3.29

(iii) \[ MR = A \exp (-kx) + B \exp (-l/x) \] ----3.30

where,

\[ MR = \text{dimensionless moisture ratio} \]
\[ x = \text{drying time, h} \]
\[ k = \text{drying constant, h}^{-1} \]
\[ A, B \& l = \text{dimensionless empirical constants} \]
\[ b_0, b_1, b_2 \& b_3 = \text{dimensionless empirical constants} \]

The parameters of the models and proposed models were estimated by using SPSS (Statistical Package for Social Science) software.
3.5.7.1. Comparison of models

The suitability of the models was evaluated and compared using the mean relative percentage deviation ($E_m$), standard error of estimates ($E_s$), randomness of residual ($e_j$) and $R^2$ values (Chen & Morey, 1989; Menkov, 2000) which are given below

$$E_m = \frac{100}{N} \sum_{i=1}^{N} \left( \frac{R_o - R_p}{R_o} \right)$$

$$E_s = \sqrt{\frac{\sum_{i=1}^{N} (R_o - R_p)^2}{df}}$$

$$e_j = R_o - R_p$$

Where,

$R_o$ = observed moisture ratio value

$R_p$ = predicted moisture ratio value

$N$ = number of data points

$df$ = degrees of freedom of regression model (number of data points minus number of constants in the model)

Data points in a plot of the residual values versus the predicted values should fall in a horizontal band centered on zero and displaying no systematic tends towards any clear pattern. If the residual plots indicate a clear pattern, the model should not be accepted (Chen & Morey, 1989; Menkov, 2000). In this study the pattern were examined by plotting the residuals with the predicted values of MR. A model was considered as good when the residual plots indicate uniformly scattered points, all error terms minimum and the $R^2$ value maximum. If all the residual plots indicate a clear pattern, then that parameter was ignored and the rest of the parameters were considered to predict performance of the models.

3.6. Deep-Bed Drying

The details of deep-bed dryer, experimental procedure and the models used for deep-bed drying were given in this section.
The dryer used for thin-layer drying studies (Fig.3.3) was modified as deep bed dryer by increasing the depth of the drying chamber from 20 cm to 40 cm to study the effect of bed thickness at the optimized drying air temperature of 80 °C (in thin layer drying) at bottom layer, 15 cm, 30 cm and 40 cm depth.

3.6.2. Experiment

This experiment was conducted to optimize the bed thickness on the basis of total time taken to dry coconuts to 6.25 % d.b. and to determine the drying characteristics of coconut in each layer (bottom layer, at 15, 30 and 40 cm depth) of deep bed. All the experiments were conducted at an air velocity of 0.5 m/s, the recommended air velocity for industrial drying of coconut (Nampoothiri, et al., 1986). All the experiments were conducted in the prevailing atmospheric conditions at the optimized drying air temperature of 80 °C. After finishing the experiment, one coconut of the dried sample was further dried in the experimental environmental condition till it gives a constant weight. This sample was used to determine the equilibrium moisture content of the sample in the experimental environmental condition. Each experiment was replicated thrice and the average values were used for data analysis.

3.6.3. Models

Three drying models (Lewis, Hustrulid & Flikke and Page) as mentioned in section 2.5.1 were selected for fitting the experimental data of deep-bed drying of coconut at 80 °C and constant air velocity of 0.5 m/s. The first model is a polynomial of third degree where as the other two are sum of two Hustrulid & Flikke models. The proposed models (3.28, 3.29, and 3.30.) were compared with the selected three thin-layer drying models. The suitability of the models was evaluated and compared as explained in section 3.5.1.4.
3.7. Copra Dryer

The design, method of fabrication and testing of a copra dryer, experimental procedure and the models used to describe copra drying were explained in the following sections. The dryer developed is shown in Plates 3.5 and 3.6.

3.7.1. Design and development of a copra dryer

A new type of dryer working on indirect heating and natural convection principles using coconut shell as fuel was designed and developed. This dryer required less amount of fuel, makes copra in short time and less expensive too. The capacity of the dryer is 1000 nuts per batch. The dryer developed has two heating chambers, which were arranged in parallel. Specially developed rolling in type fuel trays were used for burning the fuel. The dryer parameters like size of the drying chamber, size of heating chamber, ventilation holes etc. have been designed by taking into consideration, various factors like psychometric and heat transfer principles. Coconut shells were used during experiments. In fact any agricultural waste can be used as fuel.

3.7.1.1. Description of the dryer

The overall dimensions of the dismantling type rectangular frame were 2.25 (L) x 1.5 (B) and 1.5 m (H) using 40 x 40 x 3 mm equal angle iron and 20 x 5 mm mild steel flat as supporting frame. The dryer fabricated is shown in Plates 3.5 and 3.6. The rectangular structural frame was divided into four parts namely (i) Air inlet chamber (20 cm from the ground level), (ii) heating chamber (60 cm height from the ground level), (iii) plenum chamber (30 cm above the heating chamber) and (iv) drying chamber (30 cm above the plenum chamber) and it requires a housing shed of 3 x 3 m size. The dryer as well as the burning chamber have rectangular cross section. The details of list of materials required for fabrication along with the cost of each component are given in Appendix-VII.
Plate 3.5. Overall view of the copra dryer

Plate 3.6. View of the dual heating chamber of the copra dryer with fuel tray
3.7.1.2. Air inlet chamber

The dryer was fabricated with 20 cm ground clearance. This was fabricated using 20 x 5 mm M.S fiat and 16 guage G.I. sheets on all the sides for the fresh air to enter with the help of movable doors hinged on the main frame using 75 mm M.S. hinges. Hinges were provided for regulating the supply of fresh air.

3.7.1.3. Heating cum heat exchanging chamber

Above the air inlet opening, the heating chamber was provided to burn the coconut shells. The heating chamber was divided into two separate compartments of 1.40 (L) x 0.90 (B) x 0.60 (H) m and was fabricated by using 16 gauge. G.I. sheet. Two trolley type fuel holding trays made of 20 x 25 x 5 mm M.S angle and 16 gauge G.I sheet were provided to load the fuel (coconut shell). The design details of the heating chamber are given in Appendix - IX. The heating cum heat exchanging chamber was placed at a vertical inclination of 4 degree for smooth flow of flue gases to the chimney. Two separate chimneys have been provided for proper escape of fine gas and smoke. The height of the chimney was 1.5 in for better draft. Butterfly valves were provided in the exhaust pipes. A separate smoke chamber was fabricated so that smoke does not accumulate in the burning chamber and for better natural draft (Fig. 4.64).

3.7.1.4. Plenum chamber

The empty space provided above the burning chamber is known as plenum chamber. A door has been provided which was made of 20x 5 mm M.S. flat. The door was hinged to the main frame by using 3 nos. of 75 mm M.S. hinges.

3.7.1.5. Drying chamber

The top portion of the dryer is known as drying chamber. The weld mesh for stacking copra was made of 10 gauge, 25 x25 mm weld mesh. Wire mesh was also provided to avoid the falling of small copra pieces and coconut pith on the heating chamber
and for even distribution of hot air in the drying bin. On one side of the drying chamber a
door has been provided for easy loading and unloading the coconuts. The sides of the
heating chamber was covered by the 6 mm thick bamboo plywood sheets and all other parts
of the dryer was covered with 6 mm thick asbestos cement sheet to withstand high
temperatures.

3.7.1.6. Experiment

Before conducting any experiment, the heating chamber was loaded with fuel and
charged till the desired drying air temperature attained steady state. The dryer was tested for
production of copra in January to March 2003. Instrumentation as reported in section
3.5.1.2. was also used for determination of moisture content, temperature and RH. After
Finishing the experiment, one coconut was again dried in the experimental environmental
condition till it gives a constant weight. This sample was used to determine the equilibrium
moisture content of the sample in the conditions under which experiments was conducted.

For making copra, the coconuts were split into two halves and kept inverted for 4-5
minutes in order to drain the water. After the coconut water was completely drained, the
cups were stacked in the drying chamber, layer by layer in such a way that in the first two
layers, the inside of the cup faces upwards (U) and in the subsequent layers, the inside of
the cup faces downwards (n). The cups in adjacent layers are stacked in a brick-laying-
fashion, one overlapping the other. Four replicate drying trials were conducted at full load
and the average values were used to study the effect of drying air temperature of 80 °C on
drying time. The drying temperature and bed thickness were optimized in the thin layer and
deep bed drying experiment. The characteristics and quality parameters of coconut oil were
assessed as reported under thin layer drying experiment of this chapter. Drying was carried
at the prevailing air velocity at the experimental site which varied from 3.2 to 2.61 km/h.
The air velocity data was obtained from the agricultural meteorological observatory at
CPCRI, Kasaragod, Kerala situated at 10.7 m above mean sea level, 12.5 °N latitude and 75°E longitudes.

3.7.2 Performance of dryer

The thermal efficiency of the drying was calculated using the formula as given below (Patil et al., 1984 and Singh et al., 1999)

\[
\eta = \frac{\varphi \lambda (M_o - M_f)}{W C (100 - M_o)} \times 100
\]

--- 3.34

Where,

\( \eta \) = thermal efficiency of the dryer, %

\( M_o \) = initial moisture content (% wet basis)

\( M_f \) = final moisture content (% wet basis)

\( \varphi \) = Quantity of the final dried product at \( M_f \) moisture content kg

\( \lambda \) = Latent heat of vaporization in kcal / kg

\( W \) = Quantity of fuel used in kg.

\( C \) = Calorific value of fuel used in kcal / kg

The latent heat of vaporization was assumed to be 540 kcal / kg and the calorific value of shell was 4470 kcal / kg (section 4.2.3.4).

The heat utilization factor is defined as the ratio of temperature decrease due to cooling of the air during drying and the temperature increase due to heating of air. The heat utilization factor (HUF) and the coefficient of performance (COP) were calculated by using the following formulae (Chakraverty, 1988)

Heat utilization factor = \[ \frac{t_a - t_e}{t_d - t_a} \] 3.35

Coefficient of performance = \[ \frac{t_e - t_a}{t_d - t_a} \] 3.36

where,

\( t_a \) = dry bulb temperature of the ambient air, °C

\( t_d \) = dry bulb temperature of the heated air, °C

\( t_e \) = dry bulb temperature of the exhaust air, °C
3.7.3. Microbiological quality of stored copra

Copra was stored at room temperature and in the existing environmental conditions for 1, 2 and three months to study the microbial characteristics. The treatment details are given below.

M1 - dried in Smoke Dryer and stored for 1 month
M2 - dried in Smoke Dryer and stored for 2 months
M3 - dried in Smoke Dryer and stored for 3 months
SD1 - dried in Sun and stored for 1 month
SD2 - dried in Sun and stored for 2 months
SD3 - dried in Sun and stored for 3 months
CD1 - dried in Copra Dryer and stored for 1 month
CD2 - dried in Copra Dryer and stored for 2 months
CD3 - dried in Copra Dryer and stored for 3 months

The bacteria, fungi and actinomycetes population of copra was estimated by serial dilution and spread plate method. The copra samples derived from different treatments were observed for visible growth of bacteria, fungi and actinomycetes colonies. The colour and odour of these samples were also recorded. The copra cups from each treatment were sliced into pieces in such a way that all and any microbe growing on the surface was represented. Ten gram of sliced copra pieces of each treatment was put into 90 ml of sterilized water giving rise to $10^1$ dilution. Ten ml from this dilution was added to another 90 ml sterilized water to give $10^4$ dilution. Likewise serial dilutions were made to give up to $10^7$ dilution. From the $10^6$, $10^{-4}$ and $10^{-3}$ dilution flasks, 0.1 ml of aliquot was taken and spread on agar media for enumeration of bacteria, fungi and actinomycetes respectively. The media used were nutrient agar for bacteria, potato dextrose agar for fungi and Ken Knight’s Munaeir agar for actinomycetes. The chemical composition of the above media is given in Appendix section.

The population of bacteria and fungi were scored within 72 hours after incubation while those of actinomycetes between 5th and 7th day of incubation. The results are
expressed as ‘X’ x 10^n colony forming units (cfu)/ g of copra, where ‘X’ is the number of colonies and ‘n’ is dilution factor.

3.7.4. Evaluation of weather parameters

Weather data for 22 years (1974 to 2002) viz. temperature, relative humidity, wind velocity, sunshine hours and rainfall were collected from agricultural meteorological observatory at CPCRI Kasaragod situated at 12.5 °N latitude and 75 °E longitude. The average values of all these parameters were calculated for every meteorological month and were used to suggest probable months when copra dryers can be used effectively. The EMC values obtained as reported in section 3.4 was used to correlate with relative humidity of the atmosphere.

3.7.5. Models

Three drying models (Lewis, Hustrulid & Flikke and Page) given in section 2.5.1 of Chapter-II were selected for fitting the average experimental values of four replicate trials of the dryer at drying air temperature of 80 °C at prevailing constant air velocity of 3.2 to 2.61 km/h and two replicate trials were conducted at 75 % and 50 % load. Three empirical models were proposed. The first model is a polynomial of third degree where as the other two are sum of two Hustrulid & Flikke models. The proposed models 3.31, 3.32 and 3.33 were compared with the selected three thin-layer drying models.

The parameters of the models and proposed models were estimated by using SPSS (Statistical Package for Social Science) software. The suitability of the models was evaluated and compared as explained in section 3.5.1.4.

3.7.6. Statistical analysis of data

Coding and tabulation of the collected data were done as per the set standards. Taking into account the specific objectives of the study and amenability, the data were subjected to different statistical tools. These tools included mean, standard deviation,
percentage analysis, chi-square test and correlation coefficient. The data were analyzed as a completely randomized design. Statistical significance was determined at $P < 0.05$ level for analysis of variance (ANOVA) and the mean were separated using Duncan’s Multiple Range Test (DMRT). The parameters of the regression models and proposed models were estimated by using Statistical Package for Social Science (SPSS) software.

3.7.7. Cost economics

Based on the materials used and the fabrication charges of the dryer, the cost of the unit was calculated (Appendix-IV). The cost of drying of coconut in the dryer developed was worked out following standard procedure (Appendix-VII).