DESIGN DEVELOPMENT AND PERFORMANCE EVALUATION OF COPRA DRYER

A Thesis submitted to the

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DAPOLI - 415 712
Maharashtra State (India)

In the partial fulfillment of the requirements for the degree

Of

MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)
in
AGRICULTURAL PROCESS ENGINERING

by
Sarita Achyut Sane

DEPARTMENT OF AGRICULTURAL PROCESS ENGINEERING
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CANDIDATE'S DECLARATION

I hereby declare that this thesis or part thereof has not been submitted
by me or any other person to any other
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This is to certify that the thesis entitled, **"Design Development and Performance Evaluation of Copra Dryer"** submitted to the Faculty of Agriculture Engineering, Dr.Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist.Ratnagiri (Maharashtra State) in Partial Fulfillment of the requirement of award of degree of **Master of Technology (Agricultural Engineering)** in **Agricultural Process Engineering,** embodies the result of piece of bonafied research work carried out by **Miss. Sane Sarita Achyut** under my guidance and supervision. The Result embodies in this project report has not been submitted to any other university or institute for the award of degree or diploma.

The assistance and help received during the course of this project work and source of the literature have been duly acknowledged.

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LIST OF SYMBOLS

Symbols	Description
^0C	Degree centigrade
η	Efficiency
%	Percent
λ	Latent heat of vaporization
ρ_a	Density of drying air
φ	Quantity of final dried product

LIST OF ABBREVIATIONS

Abbreviation	Description
atm.	Atmosphere
A_d	Area of drying chamber
a_c	Cross sectional area of chimney
B	Breadth
B.T.P.	Bulk density true density and porosity
C	Velocity of air
cm.	Centimeter
C_a	Specific heat capacity of the air
C_v	Calorific value
d	Diameter of chimney
D_g	Geometric mean diameter
etc.	Etcetra
et al.	And others
E	Porosity
g	Acceleration due to gravity
ha	Hectare
H	Height of chimney
i.e.	That is
K	Thermal conductivity
kcal/ kg	Kilo calorie per kilogram
km^2	Squre kilometer
kg	Kilogram
kg/ m^3	Kilogram per cubic meter
K m	Kilometer
L	Length
L_s	Specific latent heat of vaporization of water
m.c.	Moisture content

mm.	Millimeter
M_i	Initial moisture content of the sample
M_f	Final moisture content of the sample
P_b	Bulk density
P_t	True density
P	Pressure difference
P_1	Actual draft of chimney
Q	Heat loss
Q_a	Volume flow rate of air required
q_e	Rate of exit air
T_i	Initial temp. of drying air
T_f	Final temp. of drying air
T_1	Inside temp. of heating chamber
T_2	Outside temp. of heating chamber
t_h	Thickness of bed
V_e	Volume of exit air
W_a	Quantity of air required for drying
W_{dr}	Average drying rate
W_f	Final weight of the sample
W_g	Initial mass of the wet coconut
W_i	Initial weight of sample
W_w	Amount of moisture to be removed
x	Thickness of material

ABSTRACT

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DESIGN DEVELOPMENT AND PERFORMANCE EVALUATION OF COPRA DRYER

by

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Drying is an important unit operation that increases the shelf life and quality of an agricultural commodity. Stored material deteriorates because of growth of microorganisms, insects or mites. Drying reduces the amount of moisture content in the commodity upto safe level by supplying the heat energy. Coconut is dried under gradual change of temperature from 55 to 70 ºC.

A study was conducted in a Dapoli taluka of Ratnagiri district to evaluate the conventional drying practices of copra making. In order to give the better solution for copra making rather than conventional methods a small-scale lab model of combined combustion and drying unit was designed, fabricated and tested. The survey was done in a Dapoli taluka to study the traditional methods of copra making. There were two common methods of copra making i.e. Sun drying and Chula drying. There were some limitations observed in the methods.

The suitable dryer was developed for copra making in the konkan region. The maximum temperature recorded in the drying chamber due to heating was 70ºC during the test period. The furnace was fired with coconut waste i.e. coconut husk and coconut shells. The moisture content of the coconut was reduced from 55% w.b. to 6% w.b. in the drying period. It was observed that average 35 hours required for the drying with average 120 kg of fuel. The quantity of drying air required was 900 kg throughout drying period. The efficiency of the dryer was calculated by taking three trials of drying. The thermal efficiency of the dryer was observed to be 25. 20%.

The copra was graded as 55% white copra, 31% brown copra and 14% dusty copra. Although the thermal efficiency is not so satisfactory, the dryer was found better compared to traditional methods due to the quality of final product and the ability to perform under adverse environmental conditions.

1. INTRODUCTION

The coconut palm (*Cocos nucieferaL.*) is widely known as the “Tree of Heaven or Kalpavriksha”. It is an exclusive means of livehood to millions of small and marginal farmers in India. The bounded relationship between a common man and the coconut palm can be perceived from the rate of coconut and its products in his social and cultural life. In the tropics perhaps no other crop has so much to offer to mankind other than the coconut. It is a versatile multipurpose palm with many different uses ranging from a staple food to an industrial plantation crop. Because of the usefulness of each and every part of this palm and the vast multitude of people that it supports through ancillary and small-scale industries, it is often considered as a tree of life.

Its main products come from the coconut, a fruit containing the nut enclosed by the husk of fibrous layers with smooth outer skin. Beneath the hard shell of the nut is the coconut meat, a white edible endosperm that has a concave free surface forming spherical hollow filled with coconut water. Coconuts are used both as tender nuts for drinking purpose, as mature nuts for household culinary purpose and for copra production. Raw fresh coconut kernel forms the largest component in the consumptions, pattern of coconut products. In Kerala, more than 25 percent of the total nut production is consumed as mature nuts for culinary uses with an average consumption of 200 to 300 nuts per household per year. In other coconut growing states, except Andaman and Nicobar Island and Lakshadweep, 75 percent of the production is consumed either as tender nuts or as mature nuts for various household purposes. Thus about 60 percent of the total production in the country is consumed as fresh nuts.

In India, coconut is cultivated in about 19, 10,000 ha mainly in southern states of Kerala, Karnataka, Tamilnadu, and Andhrapradesh. India counting 22.34% of the world’s production in coconut (Chaudhary & Mathew, 2004). The annual production is estimated nearly 13,000 million nuts. Maharashtra occupied eleventh place in area and seventh place in coconut production. The total area under coconut cultivation in the Konkan region is about 16789 ha with production of 244.4

million nuts (2000-2001). Over a period of 15 years from 1986- 87 to 2000-2001 the area increased from 6900 to 16789 ha and production increased from 76.32 million nuts to 244.4 million nuts. The productivity has increased from 52-nuts/-palm/ year to 70-nuts/palm/ year (Nagwekar et.al. 2003).

Coconut contains almost all essential vitamins and minerals, which are necessary for health. Coconut fat is made up of fatty acids of saturated, unsaturated and glycerol esters. The coefficient of digestibility of coconut oil is highest when compared with that of the other fats. The coconut protein has a biological value of 71 to 77 per cent and digestibility of 86 to 94 per cent. Coconut contains the following carbohydrates, sucrose, raffinose, galactose, glucose, fructose, pentose, cellulose, pentosans, starch dextrin and galacton. The fresh kernel contains about 7 percent sugar and it is a poor source of minerals. Fresh coconut contains 151 IU of thiamine, 1mg of ascorbic acid, (Vitamin C), traces of vitamin A and 0.2 mg of tocopheol per 100 g. Coconut proteins are high in nutritive value and are fairly rich in lysine, menthionine, and tryptophane (Menon & Pandalai 1957).

The nuts contain coconut milk – a pale whitish liquid with a strong taste of coconut. This liquid is gradually absorbed as the nuts ripen. The coconut meat is either sun dried or kiln dried and is known as copra. The copra is available in two forms i.e. ball copra and cup copra. Ball copra is obtained from mature unhusked nuts stored in the shade for 8-12 months. Cup copra is made from fresh or stored nuts by cutting the kernel into halves and drying them under the sun or special dryers or kiln. The dried coconut i.e. copra has a great market value and it is also used in the manufacture of cakes, pastries and chocolates.

Drying is an important unit operation that increases the life and quality of an agricultural commodity. Stored material deteriorates because of growth of microorganisms, insects or mites. The initial development of these pests depends on the biotic and abiotic characteristics of the freshly harvested commodity. Drying reduces the amount of moisture content in the commodity upto the safe level by supplying the heat energy. Coconut is dried under gradual increase in temperature from 55- 70 ºC in a thin layer (Patil, 1989).

Thin layer drying refers to the drying process in which all the material or particles are fully exposed to the drying air under constant drying conditions i.e. at constant air temperature and humidity. Generally, maximum upto 20 cm thickness of grain bed is taken as a thin bed (Chakraverty, 1997).

There are two commonly used traditional methods of copra making available in a country i.e. Sun drying and Kiln drying. In the method of Sun drying the coconut cups are arranged close together with a kernel facing the sun. After one or two days of drying, the shells are scooped from the nut and again nuts are kept for further drying of four to five days. The another method of copra making is kiln drying. In this method the nuts are spread on the platform and slow fire is provided at the bottom with coconut shells, husks, dried fronds etc. The process of drying is continued for a week. Copra processing is completed by bringing down the moisture to 6 to 7 percent.

The processor cannot undertake sun drying satisfactorily due to monsoon conditions as it resulted in sub standard products with dark coloured skin, damages due to fungus growth and poor keeping quality due to high moisture content. Also the unhygienic conditions in the open spaces and roadsides by the dust and other impurities are bound to affect the quality of copra, which in turn lowers the quality of copra and its oil. The method of drying over the fire also does not yield good quality copra since there is no control over the drying process besides the discolouration and sooty smell produced by direct contact with the smoke. Also these methods require a large clean yard for drying and labour required for frequent turning of the fruits. All these effects are responsible to reduce the quality of copra and overall market value.

Considering all these problems in copra making, efforts are initiated to develop a mechanical dryer, which can be suitable for copra making. Therefore the present study is undertaken to develop a suitable copra dryer with the following objectives;

(1) To study the engineering properties of coconut.
(2) To study the traditional methods of copra making in Dapoli taluka.
(3) To design and developed a copra dryer by using coconut waste (Shell &husk) as a fuel.
(4) To test the developed copra dryer.

2. REVIEW OF LITERATURE

This chapter deals with brief review of the literature pertaining to various parameters involved in the present investigation. The main thrust is given on the copra dryer. The first section deals with information regarding coconut crop its uses and coconut processing practices. The second section deals with engineering properties of coconut. In the later section, various types of dryers for copra and quality characteristics of copra are reviewed.

2.1 Coconut as a crop

Mathewkutty (1991) reported that coconut is the most important versatile horticulture crop, which provides all required amenities for human life. It is a crop for food, oil, fibre, beverage, timber and fuel. It also provides a variety of raw materials for production of an array of products of commercial importance. It is estimated that about 10 million people in the country depend on coconut farming and industry, directly or indirectly.

Mathew et.al. (2003) reported that, coconut is a traditional plantation crop grown in India for the last 30 centuries. The crop has significant role on the national economy besides its influence on the economic, social and cultural lives of millions of small farmers who form the backbone of the coconut culture and industry of the country. It acts as an enormous source of raw material for various small, medium and large-scale industries, particularly in those states where this crop is largely grown. It also provides livelihood security to millions of people in the country. Though the crop is grown in most of the states and Union Territories of the country, there is distinct difference in the pattern of distribution of the crop.

Nagwekar et al. (2003) reported that, Coconut is a major irrigated horticultural crop of Konkan region of Maharashtra. The agro climatic conditions are very congenial for its cultivation. In the Konkan region of Maharashtra state, most of the established coconut plantations are the variety West Coast tall (WCT). The Banawali, a different group of tall cultivars is a native of Goa state mainly cultivated in the Benaulim village and popularly known by the village name. It was first brought to the Sindhudurg district of Maharashtra and in the local language it was pronounced as Banawali. The coconuts of this type are smaller in size as compared to the WCT. The Banawali being a member of tall growing cultivars of coconut is highly cross-pollinated and therefore, lots of variations are noticed in colour, size, shape and yield. Maharashtra occupied eleventh place in its area and seventh place in its production. The total area under coconut cultivation in the konkan region is about 16789 ha. with production of 244.4 million nuts.

Chaudhary & Mathew (2004) reported that, India is one of the major players in the coconut trade accounting 22.34% of the world's production. Currently the crop is grown in 1.89 million ha. with annual production of nearly 13,000 million nuts. In India the crop is mainly grown in southern states of Kerala, Karnataka, Tamilnadu, and Andhrapradesh. In Kerala, average size of holding is as below as 0.22 ha. A spacing of 7.5m in the square system is recommended for coconut for optimum production.

Singh & Udhayakumar (2004) reported Coconut is commercially cultivated in 93 countries mainly on the small and marginal holdings over an area of 11.8 million hectares and reported that in the year 2002 the production of the copra was 10.26 million tonnes. In India almost the entire production of 12.6 billion nuts were consumed as a food. In Indonesia nearly 11.2 billion nuts were consumed accounting for about 74% of its production. As much as 50.8% of the total coconut area is concentrated in Kerala and the state accounts for 43.63% of the total production.

2.2 Food and nutritional value of coconut and copra

Woodroof (1970) reported that copra is obtained from the meat in the coconut palm. Processing consist of cutting open the coconut, separating the meat, drying and appropriate treatment of the husk, meat and juice components. The coconut provides an important vegetable oil. About ¼ kg. of copra is obtained per nut. About 17 to 18 lit. coconut oil is obtained from 45 kg. of copra.

Duke J A (1983) reported the composition of coconut kernel, green nut, coconut cake, coconut water and coconut leaves. The table shows the composition in detail.

Table 2.1 Proximate analysis

Constituents	Water (%)	Protein (%)	Fat (%)	Carbohydrate (%)	Fiber (%)	Ash (%)
Kernel	36.3.	4.5	41.6	13.0	3.6.g	1.0
Green nut	68-84.	1.4-2.0	1.9-17.4	4.0-11.7	0.4-3.7g	0.7-0.9
Coconut cake	10.0-13.3.	14.3-19.8	----------	32.8-45.3.	8.9-12.2%	4.0-5.7
Coconut water	95.5	0.1	0.1	4.0	---------	0.4

Table 2.2 Mineral composition

Constituents	Ca (mg)	P (mg)	Fe (mg)
Kernel	10mg	24mg	1.7mg
Green nut	11-42mg	42-56mg	1.0-1.1
Coconut cake	------	------	--------
Coconut water	29mg	37mg	0.1mg

Duke also reported that the coconut leaves contain 8.45% moisture, 4.282 ash, 0.56% K_2O, 0.25 P_2O_5, 0.28 CaO, and 0.57% MgO. The coconut water in addition to all above contain 105 mg Na, 312 K, 29 Ca, 30 Mg, 0.1 Fe, 0.04 Cu, 37 P, 24 S, and 183 mg choline Per 100 g water.

Guarte et al. (1996) stated that depending upon variety a matured coconut weights 2-3kg and is composed of about 35%husk, 12%shell, 22%meat and 25% water. On an average, fresh coconut meat consist of 50% water, 34%oil, 7.3% carbohydrates, 3.5%protein, 3.0%fibre and 2.2% ash. The coconut meat is named copra once dried. Well-dried copra contains 6% moisture and is processed into coconut oil and copra cake after storage.

Nampoorthiri and Madhavan (1999) reported that Coconut is an important source of vegetable oil used for both edible and industrial applications. It is estimated that nearly 50 percent of coconuts in India are consumed raw, while the remaining quantity is converted to copra to obtain coconut oil. Coconut meat, the endosperm of the fruit contains 20 percent carbohydrate, 36 percent fat and 4 percent protein at a moisture content of about 50 percent. A number of products are derived from coconut of which copra is the most important one. Coconut oil can be extracted either from fresh kernel or from copra. Milled copra yields coconut oil, which is extensively used for edible and cosmetic purposes, and copra cake is a valuable animal feed. Other products from coconut are the desiccated coconut, coconut cream, coconut milk powder, shell powder, activated carbon etc.

Onifade A.K. and Y.A. Jeff-Agboola (2003) reported that Coconut (*Cocos nucifera* Linn; Family *Palmae*) is one of the most extensively grown and used nuts in the world and is rated as one of the most important of all palms. Out of the 100 products that are made directly or indirectly from coconuts, eight are important in world trade. These are whole coconut, copra, coconut oil, coconut oil cake, coir, desiccated shredded coconut, coconut skim milk and coconut protein. Coconut can also be used to produce desired texture in cookies, candies, cakes, pies, salads and desserts. Coconut includes about 20% inedible shell and 72% edible portion. It contains 0.15 mg of thiamin, 1mg of ascorbic acid, traces of Vitamin A and 0.2 mg of tocopherol per 100 g sample. Coconut proteins are high in nutritive value and are fairly rich in lysine, methionine and tryptophan. The percentage of alanine, arginine, cystine and serine in the protein are higher than those in cow's milk. Hence, coconut water is used for infant feeding. Due to high content of saline and albumin, it is said to check cholera, destroy intestinal warms and relieve stomach troubles. In addition, coconut water has been found to speed up growth of *Mycobacterium tuberculosis*.

It is reported that (Anonymous, 2005) the ripe fruit of the coconut palm has a hard shell covered by a fibrous outer coat and contains an edible kernel with the coconut in the center. The shell itself is lined with a layer of rich white "meat", and the hollow at the center is filled with a thin, slightly sweet liquid that can be used as a beverage. The dried meat, called copra, is then subjected to pressing or extraction. The residue is known as copra meal almost every part of coconut palm is used. It is a primary source of food, water, drink, purifier, fluid re-hydration, isotonic, energy, tonic, fuel, and soil rejuvenator from the fiber, animal feed, and shelter. The mature coconut is a good source of iron and potassium. Approximately 86 % of the calories in coconuts is from the white meat inside the shell and are from fat calories, most of which is saturated fat. But the water of the coconut contains less than 1 %. So the pure coconut water is Cholesterol free and 99 % Fat free. Young coconut is high in calcium and phosphorus and low in fat.

2.3 Copra drying

Muller & Tobin (1980) reported that the coconut palm is grown in tropical lowlands of Asia and to some extent in America and Africa. The trees are about 25 m high and bears coconut in bunches. Each nut has a hard shell with a layer of white meat inside. When unripe, the nut contains coconut milk – a pale whitish liquid with a strong taste of coconut. This liquid is gradually absorbed as the nuts ripen. The coconut meat is either sun dried or kiln dried and is known as copra. Its oil content is very high of the order of 60 to 65%. He also reported that, copra is available in two forms i.e. ball copra and cup copra. Ball copra is obtained from mature unhusked nuts stored in the shade for 8-12 months. Cup copra is made from fresh or stored nuts by cutting the kernel into two halves and drying them under the sun or special driers or kiln. Copra dried to below 6% moisture content does not stored too long. If the moisture content exceed 8% copra is liable to mould and insect attack. He reported that, desiccated coconut is prepared from the white fleshy layer of kernel commonly known as meat. The white meat is shredded or disintegrated and dried in a hot air drier to below 2% moisture. It is used in the manufacture of the cakes, pastries, and chocolates. It is an important ingredient of a variety of Indian sweets.

Romulo (1996) stated different methods of copra making. One of the traditional methods of copra drying is sun drying. This method is commonly done during dry season and when only small quantities of coconuts are to be dried. For proper sun drying of copra, it is best to split the nuts early in the morning. Immediately after splitting, arrange the nuts close together with the kernel facing the sun on a clean pavement or flooring. After one or two days of drying, scoop the kernel from the shell with a scooping knife and dry the kernel again for another four or five more days.

Romulo also stated another method of copra drying is by using smoke dryers. There are two types of smoke dryers commonly used by coconut farmers. These are the direct and semi-direct smoke dryers. Both types have similar heating principles but differ only in design and in the manner of firing or charging fuel.

Nampoorthiri and Madhavan (1999) reported that drying must be carried out within 4 hours of splitting since coconut meat deteriorates very rapidly due to growth of mould and bacteria. Microbial activity in the form of slime is seen if temperature is only 30ºC and relative humidity around 80 percent. The greasy surface continues to develop and within 48 hours penetrating mould appears. Microbial activity is reported to be more when moisture content is above 20 percent.

Ranasinghe (1999) reported that in India, about 45,000 tonnes of ball copra is manufactured annually by slow drying whole mature coconuts with occasional artificial drying. The kiln used is similar to the Sri Lanka copra kiln, but drying carried out mainly by storage on the platform under complete shade for periods of 6-8 months.

During the rainy season artificial drying is done by burning some paddy husk or other available fuel under the platform to accelerating drying. When the coconut is dried fully, the kernel shrinks and detaches from the shell and gives a rattling sound when shaken. At this stage, the nut is carefully husked and shelled to obtain copra in the form of ball. This copra is consumed with sugar or made into chips for manufacturing sweets, etc. Ball copra is also used for religious and cultural ceremonies as well as for traditional medicines.

Annamalai et al. (2002) reported that the fresh coconut meat contains 45-55 % moisture (wet basis) and has to be dried to 6 % (wet basis) moisture level for safe storage and further processing. During rainy season, when conventional practice of open sun drying is not possible, drying by artificial method is the only possible solution for processing the produce. The existing direct type kiln dryers are not desirable as the products become inferior in quality due to smoking and improper drying. Copra and areca nuts were dried in this dryer by bulk drying as a thin bed. The dryer was tried for cardamom drying also as a preliminary study.

Shukla and Singh (2003) reported that, while copra processing fresh coconut meat having 85 to 90 % moisture content on dry basis is dried to 6 to 8 % on dry basis. The conventional practice of copra drying is by spreading the halves on mud floor in open sun, which takes 10 days. He also reported that the use of black painted polymer mat and jute cloth saved two days and one day drying time respectively compared with drying on cement floor.

Ohler (2004) stated the common methods of copra drying i.e. sun drying and second one is kiln drying which is either direct or semi-direct drying and third one is the indirect drying using hot air dryers. Sun drying is mostly depends on the weather conditions. This method is used only during the dry season and when drying only small quantities of nuts. By this method the copra can be obtained within 5-7 days. There are two types of kiln drying i.e. direct and indirect type. In the third method i.e. copra drying using hot air, the coconut meat is dried by means of uncontaminated hot air that passes through the copra bed. Since the smoke does not come in contact with the kernel, the copra produced is clean and white. If properly done, copra drying using hot air dryer produces good quality copra with 6 to 8 percent moisture content.

2.4 Physical properties of coconut

Vidhan Singh and Udhayakumar (2004) conducted the experiment on West Coast tall (WCT) coconut to study the physical properties. They studied the properties Size, Sphericity, Mass, Bulk density, true density, Porosity, Angle of repose and Coefficient of friction.

The size of the coconut was determined by taking randomly sixty-four coconuts and measuring their three linear dimensions. The geometric mean diameter and the sphericity of the fruit were calculated. The minimum and maximum length of the fruit was 16.50, 23.50 cm respectively with mean value of 20.14 cm. The geometrical minimum, and maximum diameter of fruit was 14.07, 19.67 cm with mean value of 16.38cm. The minimum, and maximum value of sphericity of fruit was 69.85, 97.0% respectively with mean value of 81% which indicates that West Coast Tall variety of coconut is like a sphere as the mean value is 81%.

The bulk density of dehusked nut, split nut copra shell and husk were determined based on the volume occupied by the bulk sample, by filling a box of 100 cm length, 75cm breadth, and 77cm height with coconut. The bulk density of kernel decreased from 464.23 to 411.674 kg/m^3. when the moisture content decreased from 94.93 to 6.15 %d.b. Also the bulk density of fruit varied from 260.57 to 268.49 kg/m^3 of de-husked nut varied from 462.40 to 496.86 kg/m^3 of coconut cups varied from 459.97 to 502. 79 kg/m^3 of copra varied from 402.96 to 417.77 kg/m^3 and that of husk varied from 109.98 to 113.86 kg/m^3. The mean values for the bulk density of fruit, de-husked nut, split nut, copra and husk were 263.57, 487.78, 497.97, 411.67, 111.83 kg/m^3 respectively. The variation in bulk density was found to be linear with the moisture content.

The true density was determined by water displacement method. The true density of kernel decreased from 524.36 to 450.31 kg/m^3. when the moisture content decreased from 94.93 to 6.15 % d.b. respectively. The variation of true density was found to be linear with moisture content.

The porosity of the bulk coconut was determined by the equation suggested by Mohsenin (1970). The porosity of the bulk coconut decreased non-linearly from 11.29 to 8.58% as the moisture content decreased from 94.93 to 6.15% d.b. It was reported that the porosity decreased with the decrease in moisture content

The angle of repose was determined for fruit by using a hollow cylinder of 100 cm diameter and 75 cm height. The cylinder was placed at the center 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 height of the cone was recorded. The angle of repose of kernel increased from 30.24 to 34.67º as the coconut kernel moisture content decreased from 94.93 to 6.15%d.b. respectively.

The experimental set up to determine static coefficient of friction consisted of a frictionless pulley fitted on a frame, a plastic hollow box of dimensions, 30x30x30 cm. loading pan and test surfaces. The hollow plastic box was placed on the test surface was filled with a known quantity of kernel and weights were added to the loading pan until the box began to slide over the test surface. The static coefficient of friction on the stainless steel surface varied from 0.43 to 0.28, on the galvanized iron sheet from 0.56 to 0.34, on the mild steel sheet from 0.62 to 0.42 and on the bamboo plywood surface from 0.66 to 0.44while the kinetic coefficient of friction on the stainless steel surface varied from 0.34to 0.17, on the galvanized iron sheet from 0.44 to 0.27, on the mild steel sheet from 0.51 to 0.35 and on the bamboo plywood surface from 0.55 to 0.37 for moisture contents between 94.93 and 6.15 % d.b. respectively. The Static coefficient of friction at any moisture content on any surface was found to be higher than the kinetic coefficient of friction within the range studied.

2.5 Copra dryers

Patil and Singh (1982) developed a tray type mixed flow electrical dryer to dry 1000 nuts per batch of 30 h. at 60ºC temperature based on the principle of natural convection used for copra drying. This dryer was fabricated especially for rainy season without affecting the quality of copra. The dryer was fabricated using the material wood, GI sheet, AC sheet, Asbestos rope and MS sheet. Components of dryer were drying chamber, air distribution unit, plenum chamber, heating unit, and blower. Drying chamber accommodated air distribution unit in the centre with copra trays on its both sides. A 1.5 hp, 2880-rpm motor was used as prime mover having the capacity of 60-m^3 /min blower. There were 20 air heaters (ordinary room heaters) of 400 W each arranged in the M.S. sheet box of 3mm thickness. The hot air then was circulated through the material on the trays.

Patil R.T. (1984a) developed a small portable, indirect type dryer using agricultural waste, as a fuel was found suitable for drying copra independent of the weather conditions. The dryer was fabricated from mild steel – angle frame asbestos sheet surface, galvanized iron sheet and a burning cum heat exchanging unit. The components of the dryer were drying chamber, plenum chamber, heating unit, and a chimney with butterfly valve to regulate the air temperature. The capacity of the dryer was 400 nuts per batch of 32h. The temperature maintained in the drying chamber during the drying period was in the range of 60 to 67ºC.

Patil R.T. (1984b) developed two types of solar dryer for drying copra. A low cost polyethylene solar dryer is made of 10 mm mild steel bar frame and 200 gauge double layered transparent cover with perforation for air circulation reduced the drying time by three days and increased the capacity by 150% compared with sun drying. Another cabinet type dryer is made of wood frame has a drying surface made of 22 gauge corrugated galvanized iron sheet painted black. The drying chamber is made of 3mm window glass on sides and 3mm acrylic sheet on top. The aluminum sheet reflectors are also provided and an arrangement of caste wheel helps to direct it towards sun throughout the day. The drying time in this dryer is reduced to four days compared with nine days in open sun drying at double spreading density. The drying temperature was 65ºC.

Annamalai et al. (2002) developed a dryer working on indirect heating and natural convection principle using dry agricultural waste as a fuel. The capacity of the dryer is to hold 1000-1200 nuts and the drying time required is 33-37 hours to make copra. The thermal efficiency of the dryer was 18.7 to 23.4%. The dryer costs about Rs. 4000/-and it requires the area about 7m^2 for housing. The dryer consist of a drying chamber, burning cum heat exchanging unit and chimney. The dryer was tested for copra and arecanut drying during August-November hourly observations on various parameters like drying air temperature at different zones, exhaust air temperature, relative humidity of ambient air and exhaust air, velocity of air flow, moisture content of the produce were taken and the drying parameters were standardized for drying copra.

Madhavan and Bosco (2004) developed a solar tunnel dryer. In this dryer fresh coconuts are dried from moisture content of 45 to 55 % to 6 % to obtain good quality copra. The capacity of the dryer is 1500 nuts/batch. The drying time for copra was 32 sunshine hours. The cost of the dryer is Rs 13650/- and the cost of drying one kg of copra is Rs. 1.15 and for Pepper Rs. 1. The solar collector and the products kept inside absorb the sunlight entering inside the tunnel dryer which in turn emit long wave thermal radiation and the polyethylene sheet prevents it from passing through. As a result, the solar energy is trapped for raising the temperature inside and used for drying the kernel kept inside. The copra dried in the solar tunnel dryer and the control trial were analyzed for its quality and the results obtained that there is significant reduction in the population of fungi, bacteria and lipolytic micro organisms in the copra sample dried with solar tunnel dryer compared to that of sun drying.

Oliver Headley et.al (2004) developed a 6 m^2 greenhouse solar dryer which is a scaled down version of a 30 m^2 solar timber dryer. The timber dryer was modified for use as copra dryer. Solar drying was chosen in order to reduce the expenditure on diesel fuel, which is normally used to dry copra to moisture content of 6% in a period not exceeding 72 hours. The results of two drying runs are reported. One was under conditions of good insolation which produced a good quality product with a moisture content of 6% after about 80 hours, the other was done under mixed weather conditions and gave a product with a moisture content of 6%after 125 hours but which showed some fungus infestation. Back up heating will be required to ensure that a good quality product is obtained reproducibly.

The dryer uses a black metal plate as a solar collector with a transparent cover of glass. Glass was chosen after the initial cover of plastic degraded in the solar ultra-violet. Air is heated in the space between the transparent cover and the metal plate and is pumped from this space into the drying chamber by two three-speed, 100W fans which can be reversed so that the tendency for the product nearer the fan to dry faster can be mitigated. The flow reversal is aided by four variable vents whose orientation can be altered so that airflow in the whole dryer is reversed when the fans are reversed. The dryer is built on a frame of 50 mm x75 mm timbers with a floor of 12 mm plywood, a roof of normal sheet glass or tempered glass and sides of transparent PVC sheet.

Thanaraj et.al. (2004) developed a small-scale rotary solar hybrid dryer for processing of copra. The components of the dryer were solar collector, furnace and heat exchanger. These three components were separately evaluated. The efficiency of the drum type solar collector was only 4%. The drum shape-drying chamber of coconut cups was designed as the solar collector as well. The drying chamber was designed to rotate manually around the axis of the heat exchanger. The maximum-recorded temperature in the drying chamber due to solar insolation was 50º C during the test period. The furnace was fired with paddy husk at different feeding rates. The average drying chamber temperature recorded at the husk feeding rates of 3kg/h, 5kg/h and 10kg/h were 43ºC, 53ºC and 62ºC and the furnace efficiencies were 43 %, 48 % and 70 % respectively. The furnace efficiency increased with increasing feeding rate. The performance of the rotary drum solar hybrid dryer was evaluated and compared against sun drying. The copra was graded as 73 % white copra, 21 % brown copra and the balance 6 % dusty copra.

2.6. Dryer performance

Sreenarayanan et.al (1989) conducted an experiment in a laboratory model thin layer drying set up for the determination of drying characteristics of copra at air flow rates of 19.57, 38.37, 82.88 m^3/hours and drying air temp. of 50, 65, 80 and 95ºC for reducing the moisture content of copra from 50 % (w.b.) to 6 % (w.b). It took only 20 h. drying in mechanical drying at an optimum temperature of 65ºC as compared to the duration of 7-10 days by sun drying. The drying air temperature and flow rate were varied by using a thermostat and by varying the speed of the blower with step pulley arrangement respectively. The weights lost during the experiments were conducted at two-hour intervals. Moisture content determinations were done as per the AOAC Method, by drying 5 gm of sample at 130+1ºC for 1 hour. The experimental results have shown positive non-linear correlation of drying time on drying air temperature and flow rate. It was also observed that the product dried at 80ºC and 95ºC hot air temperatures resulted in hard and discolouration of the copra, which are detrimental to the oil quality. Hence, the drying air temperature of 65ºCwas found to be optimum in mechanical drying. Under large-scale trial, about 2,500 nuts were dried in the mechanical drier with the agricultural waste fuelled furnace. The average hot air temperature was adjusted to 65°C at 53.46-m^3/hour-flow rate with coconut shell as fuel. It took 21 hours of drying to reduce the moisture content from 50 % (w.b.) to 6 % (w.b.).For the same reduction in moisture content under sun drying, the duration was 76 sunshine hours, which could be obtained within 8 to 10 days. The copra dried in the mechanical dryer will yield upto 65 % of oil of good quality as the drying is done under hygienic environment.

Sudaria (1993) tested a low cost semi direct type copra dryer with a capacity of 2000 nuts. It was observed that 2000 nuts required 23 hours to reduce the moisture content to 9%. This was around three days. The first two days were spent for firing the arranged coconut halves on the drying platform. On the third day, the partially dried meat with shell on the drying platform were scooped and placed back to the dryer for another firing until cooked. The fuel used to dry 2000 nuts were the husks of the nuts being dried. The average moisture content of the husk was 54.11 %. All husks of the 2000 nuts were not consumed. It only consumed, 1,243 pieces equivalent to 668.8 kg or 62.15 %. The problems of this dryer were low thermal efficiency and very expensive.

Anamalai et.al. (2002) reported testing of a natural convection dryer using agricultural waste as a fuel. In the actual operation of the dryer the fuel is burnt inside the firing tray in the burning cylinder. The temperature of the flue gases is about 180-190°C. The heat from GI sheet surface, which is at 100°C, is transferred by radiation to the surrounding fresh air entering from the bottom of the plenum chamber and this heat is transfer as a convection air current. The hot air moves up through the wet produce kept in the drying chamber and the hot air laden with moisture escapes from the top of the drying chamber. Copra dried in this dryer by bulk drying as a thin bed. The dryer was tested for copra with different parameters like, hourly observations of drying air temperature at different zones, exhaust air temperature, relative humidity of ambient air and exhaust air, velocity of air flow, moisture content of the produce etc. The drying is continuously carried out till the moisture content was reduced to 6%. The thermal efficiency of the dryer was found 18.7 % for copra. The total drying time required for drying of 1200 coconuts with two to three layers was observed to be 33-37 hours and it required about 110 kg of fuel.

Madhavan and Bosco (2004) tested a solar tunnel dryer for plantations crops. The dryer was designed to dry 1500 coconuts per batch. The solar energy is trapped for raising the temperature inside and used for drying the kernel kept inside. It was observed that when the ambient air temperature varied from 26 to 33.5°C the drying air temperature increased to 45 to 55°C and relative humidity inside the drying chamber was reduced by 20%. After 12 hours of solar drying, the kernel was shrunk and shell was partially detached from the kernel. At this stage the shell is removed manually and the kernel is further dried. It took another 20 sunshine hours for the kernel to be dried completely.

2.7 Copra quality

Thampan (1981) reported that good quality copra will yield edible oil without refining, with a free fatty acid content of less than one percent. The nutritive value of the copra cake as ruminant feed will be higher than that of poor quality copra. Copra with moisture content of 6 to 8 percent is considered as good quality copra and is not easily damaged by insects, moulds, and other microorganisms. Even moisture content of 6 to 8 percent need not cause serious trouble if subsequent storage conditions are satisfactory. Storage under dry, well-ventilated conditions for about a week will reduce the moisture content to 6 percent as long as the copra is regularly turned. Other than the moisture content, the quality of copra is influenced by several other factors of which rubberiness, case hardening and charring are decisive.

The rubberiness of the copra is determined by the variety from which the product comes and the stage of maturity of the nuts. It has been explained that the copra from certain types of dwarf palms is soft and rubbery unlike that of the ordinary tall variety. Similarly, the endosperm of unripe nuts from the tall palm is soft, difficult to dry and the driage loss is also heavy.

Gurate et.al (1996) reported that copra quality is based on moisture content and appearance and these criteria are still used in domestic and international market. Copra with 7 % moisture content and below pale white to light brown colours are regularly marketed with good returns, but those that are scorched, burned, sooty, mouldy, and with high moisture content are sold at discounted prices. Existing coconut oil (CNO) quality criteria adopted the 1990 guidelines issued by the Federation of Oils, Seeds, and Fats Association (FOFSA) which included a FFA content of less than 4 % and colour on the Lovibond scale of less than 9 red and 50 yellow.

Markose and Thomas (1999) reported that the best quality copra will be nearly white to ash white in colour free from dust or any other impurities and moisture content will be around 6 %. The oil content varies depending on the many factors. However on an average of 65 to 68 percent oil could be extracted in an expeller, from grade first milling copra. The parameters of good quality copra fixed by the Nafed are foreign matter percent by maximum limit is 1.0, Mouldy and black kernels percent count is 10.0, wrinkled kernels percent count is 10.0, chips percent by weight 10.0, moisture content percent by weight is 6.0.

Ranasinghe (1999) reported most copra producing countries have quality specifications. General requirements for good quality mill copra stipulate white coloured cups, excluding wrinkled, germinated, mouldy, charred or broken cups. Technical specifications limit moisture content to 6% minimum oil content of 68% on a dry basis, and a maximum free fatty acid content of 1% for the expelled oil. Only copra manufactured by the direct heat of coconut shell or indirect heat hot air dryers under proper conditions could conform to these specifications. Generally, copra produced in

Sri Lanka, India, Malaysia, Papua New Guinea and Pacific countries with hot air dryers conform to these specifications.

From the reviews of different authors it was observed that there were two traditional methods of copra drying i.e.sun drying and kiln drying. For the method of sun drying on an average 40-50 sunshine hours are required to make copra. Also for the kiln drying on an average 35-40 drying hours were required to make copra. For copra making the drying temperature was in the range of 60-65 °C. The optimum airflow rate was observed to be in the range of 1.2-1.6 m^3/h. The initial moisture content of the coconut on wet basis was observed to be 55% and it was reduced to 6 % wet basis for copra. The main criterion for quality of copra was the final moisture content. The copra with 6 % moisture content was considered as good quality copra. The white coloured copra was considered as good quality copra. Thus these reviews are used for the making assumptions and design of the dryer.

3. MATERIAL AND METHODS

This chapter deals with materials and methods used for developing copra dryer and it's testing. In the first section the traditional methods adopted in Dapoli taluka were described. The survey was done in the Dapoli taluka among the coconut growers to obtain the information about the practices adopted in the region for coconut drying. The second section deals with the physical properties of the coconut and coconut husk. These properties were used in the design of the dryer. The last section described the fabrication of the copra dryer and it's testing for making copra. The testing was done to determine the efficiency of the dryer.

3.1 Traditional methods of coconut drying

The study was conducted in Dapoli Taluka of Ratnagiri district.

The survey was done to understand the traditional methods adopted in the region for coconut drying.

The survey was done in the villages nearby Dapoli. The five locations were selected for the survey. The five locations were Anjarla (8km), Murud (7km), Harne (7km), Kelashi (12km), Burondi (8km). From each location two coconut growers were selected i.e. total 10 coconut growers were selected. The questionnaire was prepared for the collection of the information about the methods. The questionnaire was linked with a questions like methods used for coconut drying, seasonal adoption of methods, drying time required, type of fuel used, amount of fuel required, characteristics adopted to identify the completion of drying process, quality of product obtained, difficulties while adopting these methods, storage of copra and marketing. By collecting the all information from this questionnaire the problems in the copra making were identified. The proposed dryer was fabricated to give the solution to the traditional methods. The following flow chart shows the unit operations of traditional methods adopted in the region. (Fig. 3.1.)

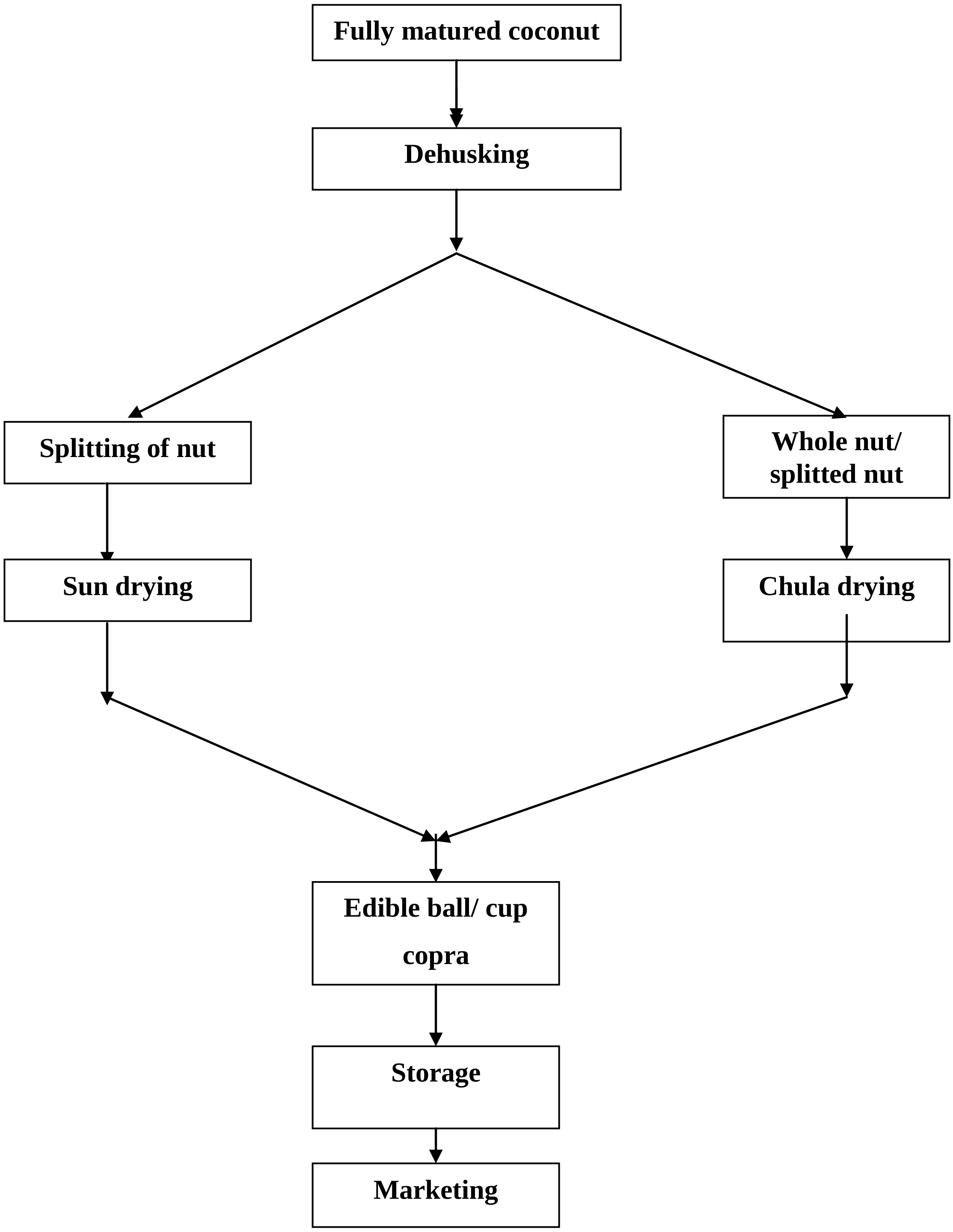

Fig. 3.1 Flow chart of traditional methods for coconut drying

The fully mature nuts of 12 to 14 months were used for making copra. Dehusking was done manually by using a locally made tool called as “Koyata.” The splitting of nuts was done with a same tool.

In the method of sun drying the splitted nuts were spread on a yard early in the morning. The coconut cups were arranged close together with a kernel facing the sun. At the time of evening the cups were collected and stored in a gunny bags. In the morning again the cups were spread on the yard. By the third or fourth day of drying the kernel gets detached from the shell and the process of drying under the sun was continued after the removal of the kernel from the shell for another five to six days. The shell was removed by scooping. Thus the process of sun drying required total eight to ten days to make copra. By this method edible cup copra was prepared. The cup copra can be stored for the three months without any spoilage by this method.

The another commonly used method for copra making is Chula drying. By this method the ball copra as well as cup copra was prepared. In this method the split cups or whole nuts were spread on the platform made up of arecanut or coconut planks called “atties” and slow fire was provided at the bottom with coconut shells, husks, dried fronds etc. The another metal sheet platform of 2.5 to 3 cm thickness also used for small scale drying.

By this process the cup copra was prepared within four to five days. The cup copra was stored in a gunny bags after complete drying till the next use. For the process of ball copra it required eight to ten days for the complete drying. After complete drying the ball copra were stored in a shade on the wooden platform above the 3 to 4 feet from ground till next use. The copra can be stored in a well condition for 5 to 6 months by this method.

Upto 80% prepared copra was used as a food in the village and remaining 20% copra was marketed in the near by the villages.

3.2 Physical properties of coconut

The physical properties of coconut and husk were measured for the design of the dryer. The properties i.e. size, sphericity, bulk density, true density and porosity were measured. Which were used in the calculations of the design aspects of the dryer. In the following section the raw material used to determine the physical properties and the methodology used is described.

3.2.1 Raw material used

Fully matured (12-14 months old) coconuts of Banawali variety were collected from the Horticulture farm of Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth Dapoli. The outer husk was removed by using locally made tool i.e. koyata.

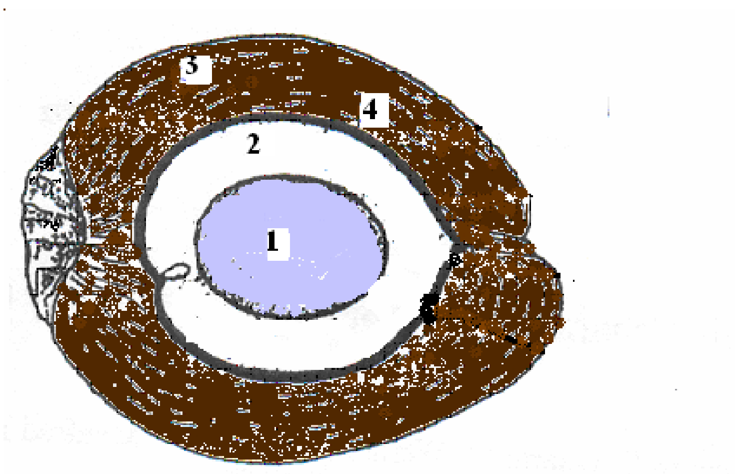

Fig. 3.2 Longitudinal section of coconut

1. Coconut water; 2. Coconut meat; 3. Coconut husk; 4. Coconut shell

The Fig 3.2 shows the terminology related with coconut. The fruit containing the nut enclosed by the husk of fibrous layers with smooth outer skin. Beneath the hard shell of the nut is the coconut meat, a white edible endosperm that has a concave free surface forming a spherical hollow filled with coconut water.

The moisture content of the coconut was determined by the AOAC method (AOAC 1975) for 130º C for 1 hour. The average moisture content of the freshly harvested nuts was in the range of 94.93 % to 81.81% w.b. The moisture content is calculated to examine the effect of moisture content on physical properties of coconut. The desired moisture content i.e. 6% w.b was obtained by drying the samples using the formula given below.

$$W_f = W_i \times \frac{100 - M_i}{100 + M_f} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where,

W_i = Initial weight of sample, kg.

W_f = Final weight of the sample, kg.

M_i = Initial moisture content of the sample, % w.b.

M_f = Final moisture content of the sample, % w.b.

3.2.2 Size

The size of the coconut was determined by taking randomly 50 coconuts and measuring their three linear dimensions namely, length (L) breadth (B) and thickness (T) using varnier calipers having 0.01mm least count. The moisture content of the sample was measured by taking randomly 10 coconuts from the sample of 50. The moisture content was calculated by equation 3.1 The geometric mean diameter D_g of fruit was calculated as per the equation suggested by Mohsenin (1970)

$$D_g = (L \times B \times T)^{1/3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where,

D_g = Geometric mean diameter cm.

L = Length, cm

B = Breadth, cm

T = Thickness, cm

3.2.3 Sphericity

The sphericity of the fruit in per cent was calculated as per the equation suggested by Mohsenin (1970)

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

$$= \frac{(L \times B \times T)^{1/3}}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(3.3)$$

Where,

L = length of coconut, cm
B = breadth of coconut, cm
T = thickness of coconut, cm

3.3 Copra dryer

The design, method of fabrication and testing of a copra dryer, are described in the following sections.

A dryer working on indirect heating and natural convection principles using coconut shell and husk as a fuel was designed and developed. The dryer was designed to dry 50 nuts i.e. 100 halves. The components of the dryer were,

1. Drying chamber
2. Heating chamber
3. Blower
4. Chimney

3.3.1 Assumptions

Assumptions were made in order to design the copra dryer. The total drying time required for the complete drying was assumed as a 24 hour. The drying time was found to be on an average 24-30 hours. The initial moisture content of the coconut on wet basis was assumed to be 55% because the average moisture content of the freshly harvested coconut was found to be around 55-60% wet basis for the Banawali variety. The final moisture content for the copra was assumed to be 6% wet basis. The drying temperature of air was assumed to be 75ºC because the optimum temperature for drying was found to be 65-70ºC in drying chamber. The thermal efficiency of the dryer was assumed to be 25% because in many studies of copra drying the range of thermal efficiency was found to be 20-25%. The heat exchanger and combustion efficiency was assumed to be 35% and 65% respectively. The calorific value of coconut was assumed to be 4500 kcal/kg. The thickness of coconut bed was assumed to be 15 cm in the drying chamber. The temperature of exhaust air was assumed to be 40ºC. The Table 3.1 shows the assumptions.

Table 3.1 Assumptions

1. Initial moisture content of coconut (w.b.)	55 %
2. Final moisture content of coconut (w.b.)	6 %
3. Drying period of coconut	24 h.
4. Drying temp. of air	75ºC
5. Temperature in drying chamber	65ºC
6. Temperature of exhaust air	40ºC
7. Latent heat of vaporization of water	2427.88 kJ/kg.
8. Calorific value of coconut waste	18837 kJ/kg.
9. Weight of 50 coconuts	25 kg
10. Thermal efficiency	25 %
11. Heat exchanger efficiency	35 %
12. Combustion efficiency	65 %
13. Drying thickness of coconut bed	15 cm

3.3.2 Amount of moisture to be removed

Amount of moisture to be removed from a given quantity of wet coconut is given by following formula,

$$W_w = W_g \times \frac{M_i - M_f}{100 - M_f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.5)$$

Where,

W_g = Initial mass of the wet coconut, kg

M_i = Initial moisture content of the coconut, % wet basis

M_f = Final moisture content of the coconut, % wet basis

3.3.3 Heat energy required

Total energy required to evaporate moisture from coconut can be determined by using following equation,

$$E_u = Q_a \times C_a \times \rho_a (T_i - T_f) \times t_d \text{ …………………………(3.6)}$$

Where,

E_u = Total energy required to evaporate the moisture from the coconut, kJ.

Q_a = Volumetric flow rate of air required, m^3/hr.

C_a = Specific heat capacity of the air at constant pressure, (kJ/kg)

ρ_a = Density of drying air, kg/m^3

T_i = Initial temperature of the drying air, ºC

T_f = Final temperature of the drying air, ºC

t_d =Total drying time required for removing the W_w kg of the water from the wet coconut, hrs.

3.3.4 Amount of fuel required

The amount of fuel required was calculated from the heat energy required and the calorific value of fuel.

$$\text{Amount of fuel required} = \frac{\textit{Heat}\text{ Energy required}}{\textit{Calorific}\text{ value of fuel}} \text{ …………………(3.7.)}$$

From the quantity of fuel required the dimensions of furnace and the dimensions of heating chamber were calculated.

3.3.5 Drying rate

The drying time, during which the drying takes place, is assumed to be 24 hrs. Average drying rate is determined from the mass of moisture to be removed and drying time by following expression.

$$W_{dr} = \frac{W_w}{t_d} \text{ ………………………………..(3.8)}$$

Where,

W_w = Amount of moisture removed, kg

t_d = Total drying time, hour.

3.3.6 Design of drying chamber

The drying chamber was designed based on the amount of coconut to be dried, density of coconut and the thickness of bed.

The floor area required for drying coconut was calculated as,

$$A_d = \frac{\text{Mass of coconut}}{\text{Density of coconut} \times t_h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.9)$$

Where,

A_d = Area of drying chamber, m^2

t_h = thickness of bed, m

3.3.7 The Quantity of air required for drying

The quantity of air needed for drying may be estimated from the energy balance equations or from the psychometric chart. Both methods are used to determine the amount of air needed to dry the particular quantity of wet coconut. The basic energy balance equation for the drying process is,

$$W_a = \frac{(W_w \times L_s)}{C_a \times \rho_a (T_i - T_f)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.10)$$

Where,

W_w = Amount of moisture to be removed, Kg

L_s = Specific latent heat of vaporization of water from wet coconut, (KJ/Kg)

C_a = Specific heat capacity of the air at constant pressure, (KJ/Kg)

ρ_a = Density of drying air, kg/m^3

T_i = Initial temperature of the drying air, ºC

T_f = final temperature of the drying air, ºC

t_d = total drying time required for removing the W_w Kg of the water from wet coconut, hours.

3.3.8 Volume flow rate of air required

Volume flow rate of air can be determine by considering weight of air and total drying time is given as follows,

$$Q_a = \frac{W_a}{t_d} \text{ ……………………………………………(3.11)}$$

From the amount of drying air required and volumetric flow rate the capacity of blower was calculated.

3.3.9 Chimney

Since airflow rate in the dryer takes place due to the draft caused by the pressure difference between outside cold air and inside hot air.

$$P = 0.000308 \times g \times (T_i - T_f) \times H \text{ …………………………….(3.12)}$$

Where,

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

g= acceleration due to gravity 9.81 m/s^2.

H= height of the chimney, m.

Actual draft will be assumed to be 80% of this draft (P).

Actual draft (P_1)=0.8 x P.

Velocity of exit air (c)=(2 x P1/ ρ_e)$^{0.5}$

Volume of exit air (v_e)= quantity of air in kg / ρ_e.

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

Cross sectional area of chimney (a_c)= q_e / c

The diameter of the chimney was decided by the following equation.

$$d = \left(\frac{4 \times a_c}{\pi}\right)^{0.5} \text{ ………………………….(3.13)}$$

Where,

c= velocity of exit air, m/s.

v_e =volume of exit air, m^3

q_e= Rate of exit air, kg/m^3

a_c = cross sectional area of the chimney, m^2

ρ_e = density of exit air, kg/m^3.

So with the above equation diameters d and height H of chimney was determined.

3.3.10 Insulation

The thickness of insulation was determined by considering heat loss from the heating chamber. Before insulation the trial was taken for the drying but it was observed that there was a considerable heat loss from the heating chamber and the time required for the drying was too long. There fore to avoid heat loss from the heating chamber the insulation was necessary. Considering the previous heat loss the thickness of the insulation was decided. Considering the thermal conductivity the asbestos sheet was used as a insulating material. The thickness of the insulation was determined by the following formula.

$$Q = \frac{K \times (T_1 - T_2)}{x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.14)$$

Where,

Q = Heat loss, watt

K = Thermal conductivity of material, W/m°K

T_1 = Inside temp. of heating chamber, °K

T_2 = Outside temp. of heating chamber, °K

x = Thickness of material, m.

3.4 Fabrication of the dryer

The fabrication of the dryer was completed in the workshop of College of Agricultural Engineering and Technology, Dapoli.

The drying chamber was fabricated by using a mild steel (M.S.) sheet. The sheet used is of 20 gauge i.e. 1.00 mm. Two sheets were required for the fabrication of the dryer. Angle frame of 1” x 1” was prepared and then sheets were fitted in the frame as per the dimensions. The heating chamber was fabricated with the mild steel (M.S.) sheet of 18 gauge i.e.1.25 mm was used. The sheet was fitted in a angle frame of 1”x1”. Three sheets were required for the fabrication of the heating chamber.

For the fabrication of the fuel tray 10 mm x 10mm mild steel square rod and 10mm x 10mm mild steel round rod were used. The rods were welded to form a fuel tray. Copper sheet was used for the fabrication of the air distribution pipe. The air distribution pipe was used to supply the heated air in a drying chamber. G.I. sheet of 18 gauge i.e. 1.25 mm was used for the fabrication of chimney. The chimney was fitted on the heating chamber as a outlet for the smoke.

After the fabrication of the all parts the drying chamber was connected to the heating chamber through copper pipe. On the another side of the pipe the blower was attached for the uniform circulation of the air. The chimney was attached on the heating chamber as an outlet for the smoke. The fuel tray was fitted below the air distribution pipe in the heating chamber.

Thus the overall construction of the dryer fabricated is shown in Fig 3.2. The side elevation from the blower side and from the drying chamber side was shown in the Fig 3.3

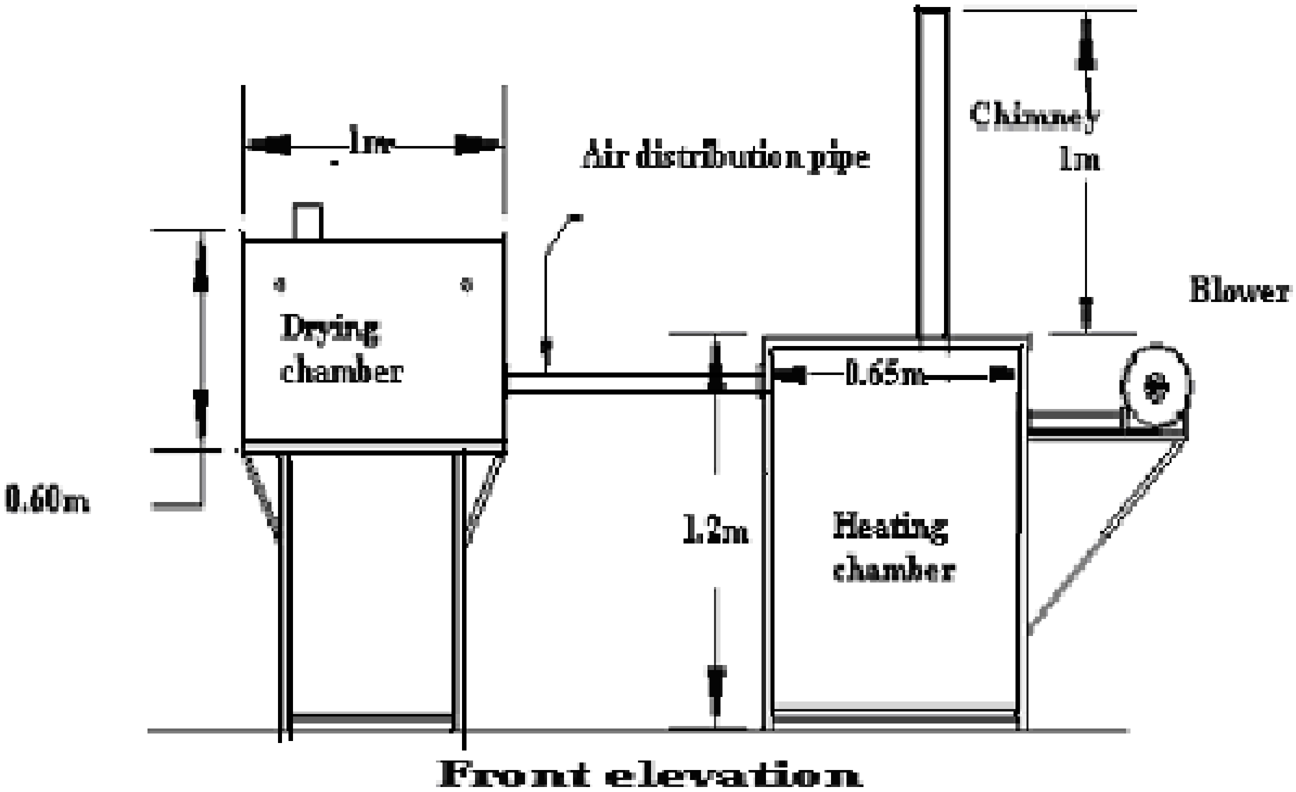

Fig. 3.2 Overall view of the copra dryer

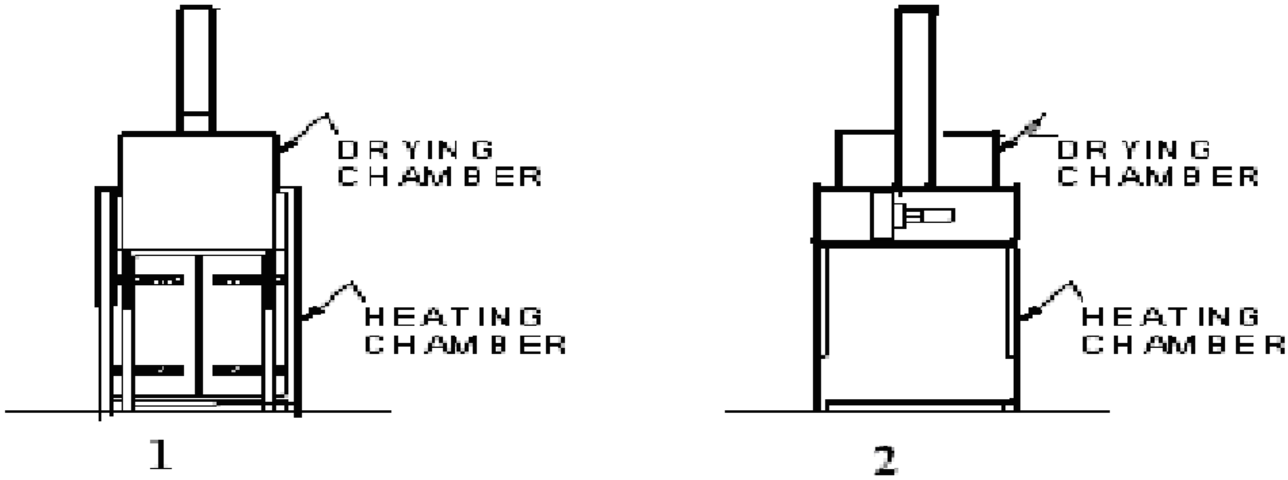

Fig. 3.3 Side elevation of copra dryer

1. Side elevation from drying chamber   2. Side elevation from blower side

3.5. Material required for the fabrication

The material used for the fabrication of the dryer was listed below in the Table 3.2. The fabrication was done in the workshop of College of Agricultural Engineering and Technology, Dapoli. The material used for the each separate part of the dryer was given below.

The available material was used for the fabrication of the dryer. The assembling was done after fabrication. The drying chamber and heating chamber were connected each other by the air distribution pipe. The blower was connected to the heating chamber by a pipe. The insulation of determined thickness was provided to the heating chamber to avoid heat loss.

Table3.2 Material used for the fabrication

No.	Design part	Material required	Quantity
1.	Drying chamber	1.M.S. Sheet 20 Gauge (1.00 mm)	2 sheets
		2.Angle frame 1”x1” (0.25 mm x 0.25 mm)	7 kg.
2.	Heating chamber	1.M.S. Sheet, 18 Gauge (1.25 mm)	3sheets
		2.Angle frame 1”x1”	10 kg.
3.	Fuel tray	1.M.S. Square rod 10 mm x 10mm (no. 8)	6 kg
		2. M.S. round rod 10 mm x 10 mm (no.15)	8kg
4.	Air distribution pipe	Copper pipe of dia. 0.10 m and 0.75 m	6.7 kg
5.	Chimney	G.I. sheet 18 Gauge	½ sheet.

Thus the overall view of the dryer after fabrication and assembling is as shown in plate no 3.3.

3.6 Performance of the dryer

The dryer was tested for its performance of drying. The three trials were conducted for making copra. The trials were conducted at three airflow rates. For the trial 50 fully matured coconuts i.e. 100 halves of Banawali variety were selected. The nuts were dehusked with the help of koyata at early morning then these nuts were splitted into two and placed in a tray for draining purpose for 15 minutes.

Initially six halves were selected and the moisture content was determined. The chopped sample of 5 gm was selected for the determination of moisture content.

The suitable airflow rate was selected for blower and the dryer was run empty to attain the desired temperature i.e. 65º C after attaining the temperature the halves were arranged on a tray in the drying chamber. The maximum bed thickness was 15 cm. The six halves were put at six different locations in the drying chamber. At each predetermined interval the weight loss of the each halves was measured and the loss of moisture content was determined. The Plate 3.5. shows the arrangement of cups in the drying chamber.

3.6.1. Temperature measurement

In the drying chamber the temperatures were measured at different locations for the interval of 15 minutes as shown in Fig 3.4 using digital thermometer. Also the relative humidity in drying chamber and atmospheric relative humidity of ambient temperature was measured. The dryer was run for 8 hours in a day. The fuel was feed in a fuel tray for continuous burning and heating normally at every 2 hours. The trial was continued till the moisture content of coconut was reduced to final moisture content of
6 %w.b.

The Plate 3.5 shows the temperatures readings taken in the drying chamber. In the drying chamber the temperatures were measured at three locations as shown in Fig 3.4. The temperatures were measured by digital thermometer having range –50 to 150ºC. The temperatures were measured to study the temperature profile in the drying chamber.

3.7. Instruments used for measurement

3.7.1 Digital thermometer sensors

Thermocouple sensors were used in measuring the temperature inside the drying chamber. The sensors were of Thermo guard and the temperature range was –50 to 150^{0}C. The length of the sensor was 15 cm with a wire of length of 1m. The temperatures at two locations in drying chamber were measured.

3.7.2 Relative humidity and temperature sensor

Relative Humidity and temperature sensor was used to measure the RH in the drying chamber and the atmospheric relative humidity. The instrument was manufactured by MEXTECH-DT-615. The humidity measurement range was 5 to 98% with an accuracy of ± 3.5%. The temperature range was –20 to 199.9^{0}C with an accuracy of ±3%.

3.7.3 Oven

A hot air oven was used in the measurement of moisture content. The oven was hot air, cabinet type manufactured by Quality Instruments, Kudal.

3.7.4 Center infrared thermometer

This laser thermometer was used to measure the temperature of the burning husk and temperature at fuel tray. The output was less than 1 mw and the distance spot for this was 8:1. This was operated at 630 to 670 nm. This was manufactured by Class II laser products.

3.7.5 Copra moisture meter

The copra moisture meter was used to measure the moisture content of the copra. The instrument was manufactured by CPCRI Kasargod Kerla. The model was CMM-KP21Vg (KEPAGRO). The range was from 0 to 40 % moisture content.

3.8. Efficiency of the dryer

The overall efficiency of the dryer was calculated using the formula given by Sing et.al. (1999).

$$\eta = \frac{\varphi \times \lambda (M_i - M_f)}{W \times C \times (100 - M_i)} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.15)$$

Where,

η = Overall efficiency of the dryer, %.

M_i = Initial moisture content (% wet basis)

M_f = Final moisture content (% wet basis)

φ = Quantity of the final dried product at M_f moisture content, kg

λ = Latent heat of vaporization in kcal/kg

W = Quantity of fuel used in kg.

C = Calorific value of fuel used.

3.9. Quality of copra

In the performance of the dryer with the machine efficiency the quality of the commodity is evaluated. The copra quality is measured with the parameters Colour, Appearance, Smell and Test by visual sence. The copra was graded based on SLS 612: 1983.The grades of the copra were, White copra, Brown copra and dusty copra. The copra was graded in three colour i.e. white, brown and dusty copra.

3.10 Statistics

The experiment was done to design, fabricate and test the dryer for drying copra. The main purpose of this lab scale model was to dry the copra. For this purpose the dryer was tested by running the three trials at three different flow rates. So the statistical design was not applicable to these trials. In future the more trials with replications will be taken and then statistical design may apply for the better results.

4. RESULTS AND DISCUSSIONS

The results obtained in the present investigation were analyzed and presented for discussion. The results include data on traditional methods of coconut drying in Konkan region, engineering properties of coconut. Design details of the developed copra dryer and the testing of the dryer these parameters are discussed under following headings.

4.1 Evaluation of traditional methods of coconut drying

The traditional methods of copra making in the region were studied by making a survey. There were two general methods used for the copra making in the region. The problems in the methods and observations were recorded in the methods.

Table 4.1. Results of traditional methods

No.	Results obtained	Sun drying	Chula drying
1	Quantity dried, kg	50	50
2	Drying time required, hours	48	33
3	Expenditure (Labour + fuel) Rs.	200	300
4	Quantity of fuel required, kg	No fuel	110
5	Shell removed on	Third day	Second day
6	Dried quantity, kg	41	44

The two traditional methods were evaluated as sun drying and chula drying. From the above table it can be stated that, the total quantity of 50 kg was taken for making copra. That is 50 kg of fresh harvested nuts were taken to make copra. The nuts were split into two and kept for a drying. In the method of sun drying the halves were spread in a yard on the wooden platform. In the method of chula drying the halves were spread on a metal sheet and that sheet was kept on a big Chula. In the sun drying the cups were kept facing towards sun but in the chula drying the cups were kept facing down for proper drying.

There was no standard method to measure the moisture content in the traditional methods. Only on appearance and the texture of the copra the drying was confirmed. The total time required for the drying in the sun drying was observed to be 48 sunshine hours i.e. approximately six days. In the sun drying the cups were stored in gunny bags at night times as there was no solar energy available. In the chula drying the total drying time was observed to be 33 working hours i.e. approximately four days. There was no fuel required for the sun drying, as it was a natural drying. In the chula drying the coconut husk, coconut shells, fronds, were used as a fuel for burning purpose to get energy. The total quantity of fuel required for the drying of 50 kg coconuts was 110 kg.

It was observed that in the sun drying the shell was removed on third day where in the chula drying the shell was removed on a next day of drying. After removing the shell in the sun drying the cups were kept facing down to the sun. And in the chula drying also the cups were kept facing up to the sheet. The thickness of sheet used in chula drying was max up to 2.5 to 3 cm.

The total expenditure found in the two methods was 200 rupees in sun drying including only labour charges because there was no fuel cost involved in this method. In the chula drying it involves labour cost as well as fuel cost there fore the total expenditure required was about to be 300 rupees.

After drying the total quantity of dried coconut i.e. copra was observed to be around 41 kg in the sun drying and around 44 kg in the chula drying. The difference in final quantity was observed because of losses in sun drying due to insects damage, animal damages and dust infection. There was no such losses were observed in the chula drying.

The final quality of copra was decided only by colour and texture of the copra. It was noticed that the copra obtained from the chula drying was better in texture and crispy in nature because there was a even drying of copra in this method compare to sun drying. In the sun drying the texture of copra was not so crispy and some what moist as compare to chula drying.

The major problems observed in the sun drying were uneven drying due to fluctuations in daily solar energy and the losses due to insect damage, animal damage etc. Also sun drying required frequent turning of the cups in a day for proper drying. In the chula drying there was a big problem of smell of smoke to the copra because in this method there was a direct exposure of coconut to hot gases. In the method of chula drying the colour of the copra was white compare to sun drying.

Thus from the overall observations it was observed that these two were the common methods used in the Dapoli region. It was observed that though there was more expenditure the chula drying was the best method in this region. This method can be operated in the rainy season but not so effective in rainy season but the sun drying was totally depending upon the atmospheric condition.

In this region the prepared 80 to 85% copra was mostly used as a food. The remaining 20 to 15 % copra were marketed in near by areas. The cost of copra per kg was around 65 Rs.

4.2. Physical properties of coconut fruit, coconut husk

The dimensions of the coconut were measured with the help of vernier caliper having 0.01mm least count. The sample size was 50 coconuts. The minimum, maximum and mean length of the fruit was 16.50, 23.50, and 20.14 cm respectively. The minimum, maximum and mean breadth of the fruit was 13, 18 and 14.75 cm respectively. Whereas there was wide variation with respect to fruit weight, the minimum, maximum and mean values were, 535, 1200, 835 gm respectively.

4.2.1. Size

The geometrical minimum, maximum and mean diameter of fruit was (D_p) 14.07, 19.67and 16.38 cm respectively. The geometrical mean diameter value calculated by using the equation proposed by Mohasenin (1970).

4.2.2 Sphericity

The minimum, maximum and mean value of Sphericity of fruit calculated using equation proposed by Mohasenin. The values were in the range of 69.85, 97.0 and 81% respectively which indicates that Banawali is like a sphere as the values are in the range of 69.85% and above. Thus for all practical purposes the nuts of Banawali can be considered as a spherical.

4.2.3. Mass of fifty-split coconut

The mass of fifty split nuts was in the range of 19.75 to 21.51 kg with a mean value of 21.07 kg. Thus the mass of 1000 coconuts will be useful in calculating the total load on the machine.

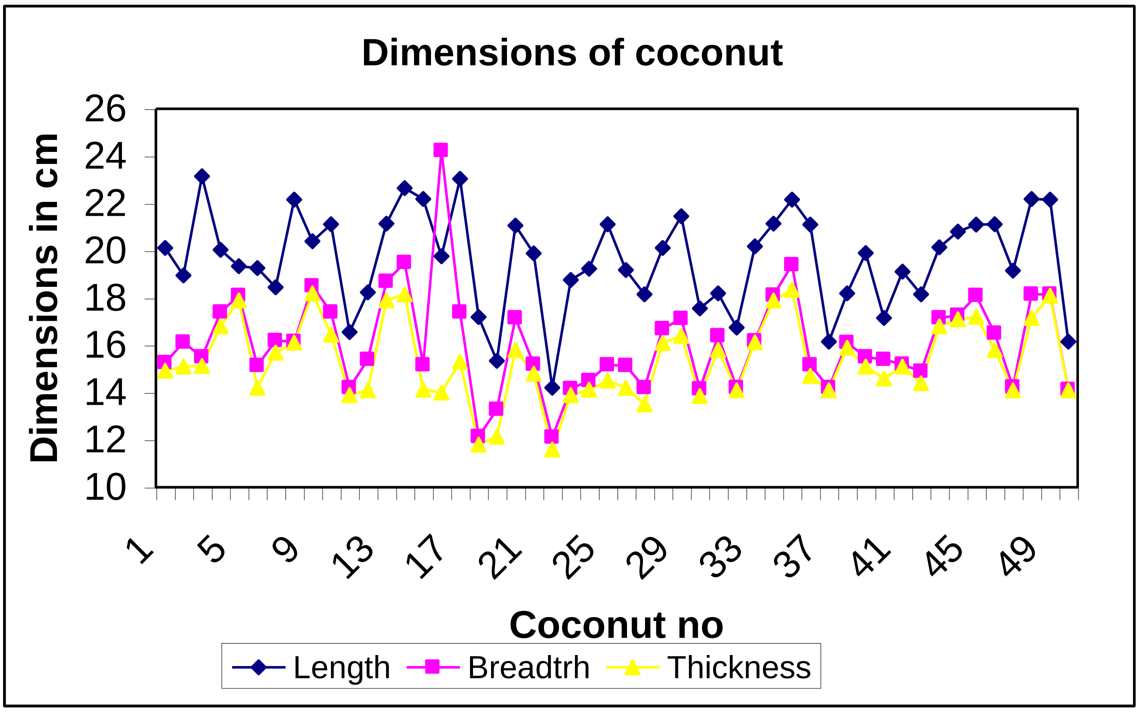

Fig 4.1 Variation in dimension of coconut

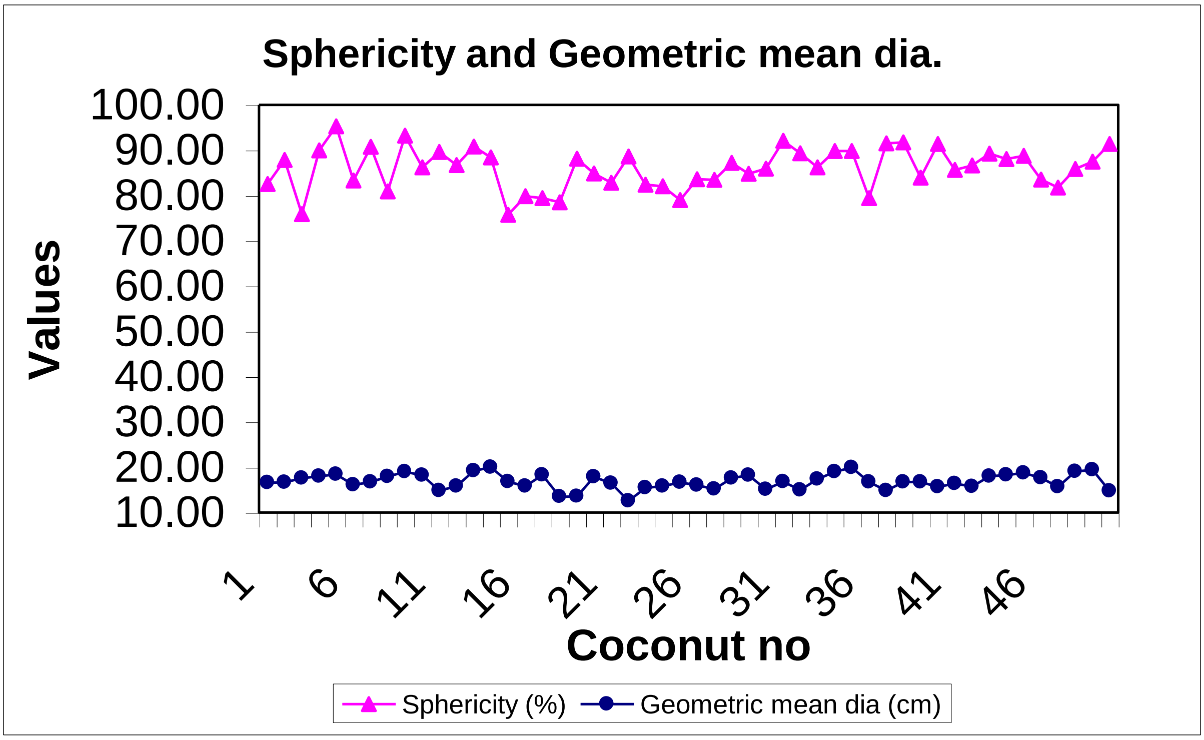

Fig 4.2 Variation of Sphericity and Geometric mean diameter.

4.3 Design of the dryer

The dryer was designed on the basis of calculated properties and the assumptions made.

4.3.1. Amount of moisture removed

Amount of moisture to be removed from a given quantity of wet coconut to bring the moisture content to a safe storage level in a specified time is given by following formula,

$$W_w = W_g \times \frac{M_i - M_f}{100 - M_f}$$

There fore,

$$W_w = 25 \times \frac{55-6}{100-6}$$

$$\mathbf{W_w = 13.03\ kg}$$

4.3.2 Amount of heat required

$$E_u = Q_a \times C_a \times \rho_a (T_i - T_f) \times t_d$$

$$E_u = 35.92 \times 1.005 \times 1.043 \times (75-40) \times 24$$

$$\mathbf{E_u = 31634.91\ kJ.}$$

4.3.3 Amount of fuel required

The amount of fuel required was calculated from the heat energy required and the calorific value of fuel.

$$\text{Amount of fuel required} = \frac{31634.91}{18837}$$

$$\mathbf{= 1.67\ kg.}$$

The calorific value used is in kJ/kg.

Considering the thermal efficiency, heat exchanger efficiency and combustion efficiency. The total quantity of husk required for given drying time is 43 kg.

There fore approximately 2kg.hr fuel is required.

Amount of fuel required = **2 kg/hr.**

4.3.4 Furnace volume

To accommodate the quantity of husk and to continuously burn husk for at least two hours the fuel tray was designed. The overall dimensions of the fuel tray were 0.60 m (Length), 0.80m (breadth) and 0.60m (Height).

Considering the free space and easy accommodation of air distribution unit and fuel tray the Heating chamber was designed. The overall dimensions of heating chamber were 0.65m (Length), 1.00 m (breadth) and 1.2m (Height). The heating chamber was connected to the drying chamber through air distribution pipe.

4.3.5 Design of drying chamber

The area of drying chamber was calculated based on amount of coconut dried, density of coconut and the thickness of bed.

$$A_d = \frac{\text{Mass of coconut}}{\text{Density of coconut} \times t_h}$$

The amount of coconut dried = 25kg.

Density of coconut = 402kg/m^3

Thickness of bed =0.15m

$$A_d = \frac{25}{402 \times 0.15}$$

$$\mathbf{= 0.44m^2}$$

Considering free space for the air circulation. The overall dimensions of the drying chamber were, 1.00m (Length) 0.55m(Breadth) and 0.60m(height). The wire mesh is fitted inside the drying chamber used as a platform for the copra with dimensions of 0.95m (Length) and 0.52m(breadth). The drying chamber is connected with a heating chamber with air distribution pipe.

4.3.6 The Quantity of air required for drying

The quantity of air needed for drying may be estimated from the energy balance equations or from the psychometric chart. Both methods are used to determine the amount of air needed to dry the particular quantity of wet coconut. The basic energy balance equation for the drying process is,

$$W_a = \frac{(W_w \times L)}{C_a \times \rho_a (T_i - T_f)}$$

$$W_a = \frac{13.03 \times 2427.88}{1.005 \times 1.043 \times (75 - 40)}$$

$$\mathbf{W_a = 862.28\ kg}$$

$$\mathbf{= 900\ kg}$$

4.3.6.1 Volume flow rate of air required

Volume flow rate of air can be determine by considering weight of air and total drying time is given as follows,

$$Q_a = \frac{W_a}{t_d}$$

$$Q_a = \frac{900}{24}$$

$$\mathbf{Q_a = 37.5 = 38\ m^3/hr.}$$

From the volume flow rate of air and quantity of air required the capacity of blower was calculated. The capacity of blower was **0.70 HP**

4.3.7 Design of chimney

For the design of chimney the pressure draft was calculated by considering the inside temp of gases in chimney and outside temp. of flue gases. From the psychometric chart the pressure draft was calculated as ,

P = 1.45 pa.

From the pressure draft the height of chimney was calculated, The height of chimney was calculated by using the equation 3.12.

$$\mathbf{H = 1m}$$

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

$$P_1 = 0.80 \times 1.45$$

$$\mathbf{P_1 = 1.160\ pa.}$$

The velocity of exit air,

$$C = \left(\frac{2 \times 1.160}{1.176}\right)^{0.5}$$

$$\mathbf{C = 1.4\ m/s}$$

Volume of exit air,

$$V_e = \frac{0.697}{1.176}$$

$$\mathbf{V_e = 0.5928\ m^3}$$

Rate of exit air,

$$q_e = \frac{V_e}{\text{drying time}}$$

$$q_e = \frac{0.5928}{24}$$

$$\mathbf{q_e = 0.0247 m^3/hr.}$$

Cross sectional area of chimney

$$\mathbf{a_c} = \frac{0.0247}{1.4}$$

$$\mathbf{a_c = 1.76 \times 10^{-2}\ m^2}$$

Diameter of chimney was calculated using equation 3.13

$$\mathbf{d = (4 \times a_c/\pi)^{0.5}}$$

$$\mathbf{d = 0.15m}$$

4.3.8 Insulation

The thickness of insulation was calculated considering heat loss without insulation. The asbestos sheet was used as a insulating material. The thermal conductivity of asbestos is 0.117 W/m^0k. The temperature inside the heating chamber was found to be 450^0C and out side temp. was 150^0C. The heat loss was 1500W.

Therefore the thickness of insulation was,

$$Q_a = \frac{K \times (T_1 - T_2)}{x}$$

Therefore,

$$X = \frac{0.117 \times (450 - 150)}{1500}$$

X = 23.4 mm = 25 mm

Therefore,

The 25 mm thick asbestos sheet was used as insulation for heating chamber.

Thus the overall view of the dryer with insulation to the heating chamber is as shown in Plate 4.1

Plate 4.1 Copra dryer with insulation

Plate 4.2 Drying chamber

Plate 4.3 Heating chamber and fuel tray.

4.8 Testing of dryer

The dryer was tested for the three trials at three different airflow rates. The size of sample for the trial was 50 coconuts i.e. 100 halves. The moisture content was reduced from 55% w.b. to 6% w.b. Three trials were taken at different air flow rates. The moisture content was calculated at every two hours of interval. The temperatures were noted at every 15 minutes interval in the drying chamber. The efficiency of the dryer was calculated by the formula given in section 3.8.

4.8.1. Trial first

The sample size for the first trial was 50 coconuts i.e.100 halves. The total weight of the fifty coconuts was 22.30 kg. The initial moisture content was calculated by the AOAC method for 130º C for 1 hour. The 5 gm sample was taken and chopped to calculate the initial moisture content.

Table 4.2 Initial moisture content of the sample trial 1

No	Initial wt of the box with sample (gm)	Final wt. of the box with sample (gm)	Moisture content (%) (w.b.)
1	65.18	62.90	58.2
2	55.75	53.12	60.7
3	56.10	54.12	61.45
4	65.76	63.24	59.76
5	53.20	50.78	60.23
6	63.90	60.98	62.97
		Avg	**59.24**

The trial was carried out to reduce the moisture content from 59.24% w.b. to 6% w.b. The fuel required was 130kg to dry the 50 coconuts. The trial was conducted at the airflow rate of 1.8m^3/min. Total hours required for the drying was 37 hours.

The thermal efficiency of the system was calculated by equation 3.15

$$\eta = \frac{\varphi \times \lambda (M_a - M_f)}{W \times C \times (100 - M_a)} \times 100$$

where,

M_a = Initial moisture content (% wet basis) = 59.24 %

M_f = Final moisture content (% wet basis) = 6%

φ = Quantity of the final dried product at M_f moisture content = 16.7 kg

λ = Latent heat of vaporization in = 587 kcal/kg

W= Quantity of fuel used = 130 kg.

C = Calorific value of fuel used = 4500 kcal/kg.

$$\eta = \frac{16.7 \times 587 \times (59.24 - 6.00)}{130 \times 4500 \times (100 - 59.24)} \times 100$$

= **21.88%**

Therefore the thermal efficiency of the system was found to be **21.88%**

The moisture content was observed at every 2 hours of interval. The graph was plotted to check the moisture loss with respect to time.

Table 4.3. Average moisture content verses Time for test 1

No.	**Time (hour)**	**Average Moisture**
		Content (% w.b.)
	First day	
1	9.00am	61.25
	11.00am	57.59
	1.00pm	54.69
	3.00pm	49.91
	5.00pm	45.45
	6.30 pm	40.81
2	**Second day**	

	9.00am	36.43
	11.00am	31.98
	1.00pm	28.37
	3.00pm	26.3
	5.00pm	24.36
	6.30pm	21.83
3	**Third day**	
	9.00am	19.96
	11.00 am	16.96
	1.00pm	14.9
	3.00pm	14.73
	5.00pm	13.22
	6.30 pm	12.87
4	**Fourth day**	
	9.00 am	8.82
	11.00am	6.75

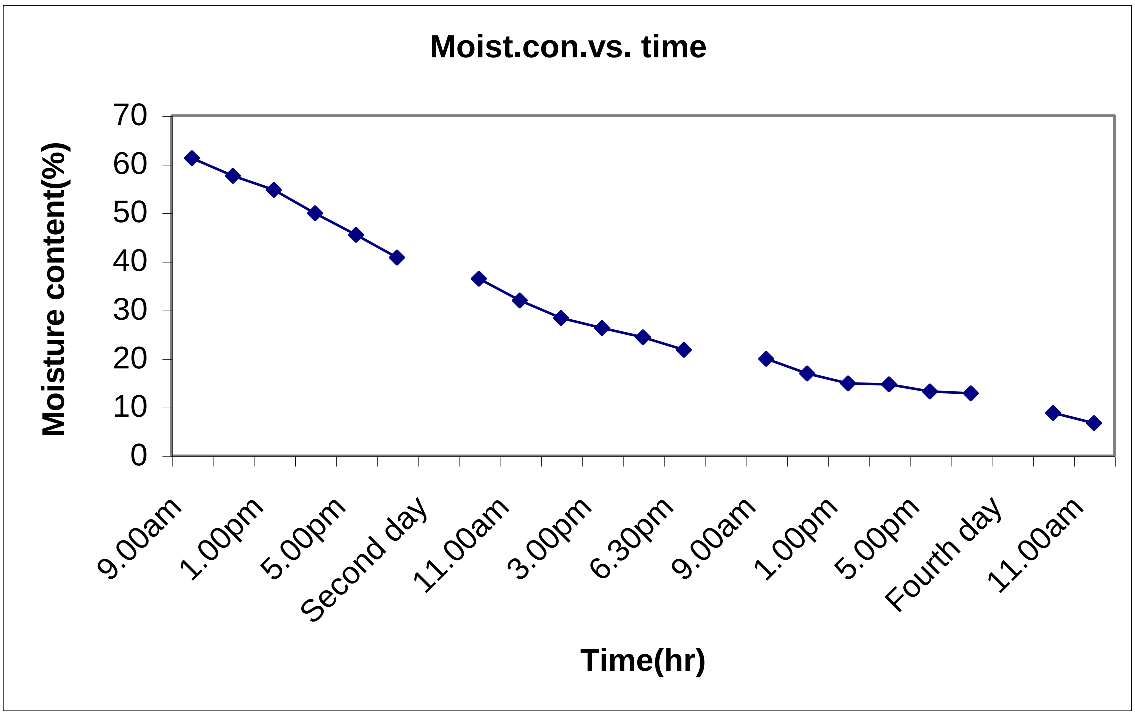

Fig 4.9. Moisture content verses time Trial 1

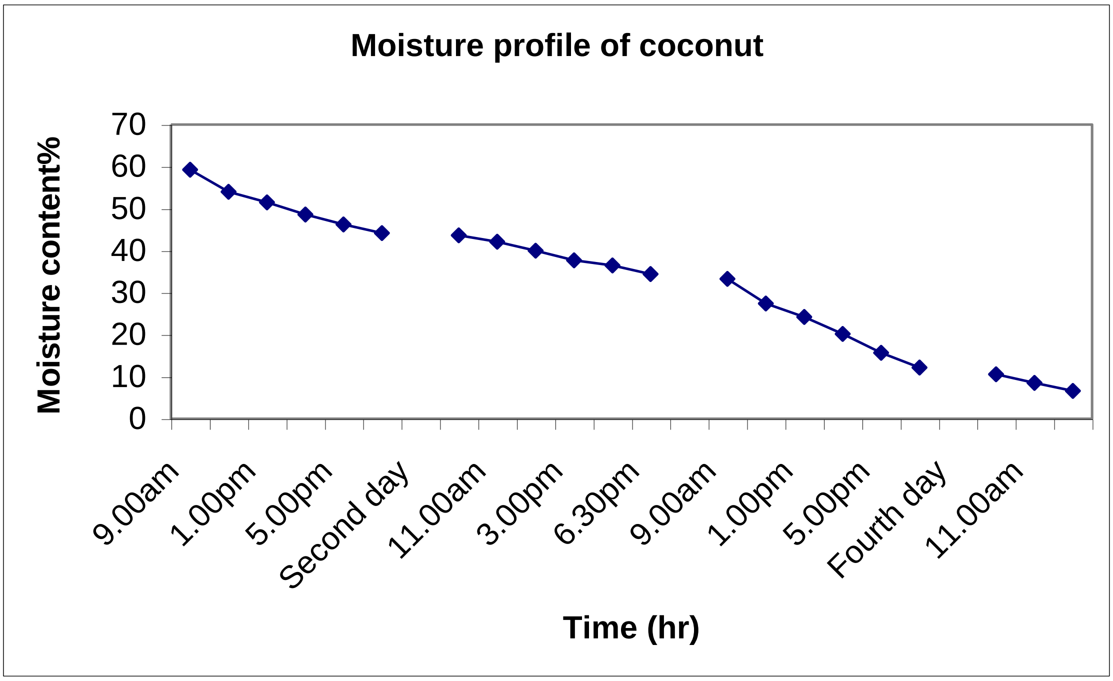

Fig 4.10 Moisture content verses time Trial 2

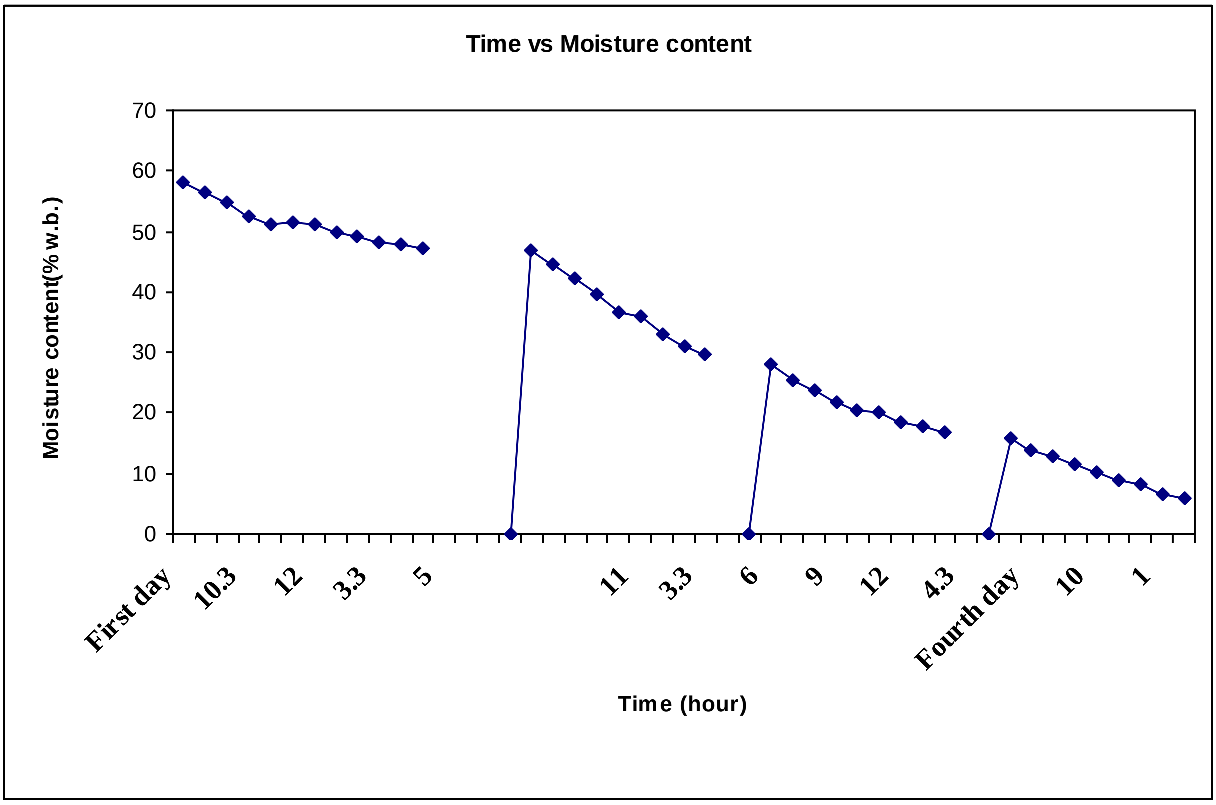

Fig 4.11 Moisture content verses time Trial 3

From the Fig 4.9 it was observed that at the first fifteen hours there was a fast removal of moisture from coconut as shown in graph. At the last stage there was very low rate of removal of moisture from the coconut.

The quality of copra was evaluated by visual sense. The copra was graded as per the SLS: 612 1983 standard. The copra was graded in three categories i.e. White copra, Brown copra and Dusty copra.

Table 4.4. Grade of copra.

Trial 1	White copra	Brown copra	Dusty copra

	48	**35**	**17**

4.8.2. Trial second

The sample size for the first trial was 50 coconuts i.e.100 halves. The total weight of the fifty coconuts was 24.10 kg. The initial moisture content was calculated by the AOAC method for 130º C for 1 hour. The 5 gm sample was taken and chopped to calculate the initial moisture content.

Table4.5. Initial moisture content of the sample trial 2

No	Initial wt of the box with sample (gm)	Final wt. of the box with sample (gm)	Moisture content (%) (w.b.)
1	67.18	64.90	59.2
2	55.75	53.12	60.7
3	56.10	54.12	61.45
4	65.76	63.24	60.76
5	54.20	51.78	61.23
6	62.90	60.98	62.97
		Avg	**61.25**

The trial was carried out to reduce the moisture content from 61.25% w.b. to 6% w.b. The fuel required was 115kg to dry the 50 coconuts. The trial was conducted at the airflow rate of 1.1m^3/min. Total hours required for the drying was 33 hours.

The thermal efficiency of the system was calculated by equation 3.15

$$\eta = \frac{\varphi \times \lambda (M_a - M_f)}{W \times C \times (100 - M_a)} \times 100$$

where,

M_a = Initial moisture content (% wet basis) = 61.25 %

M_f = Final moisture content (% wet basis) = 6%

φ = Quantity of the final dried product at M_f moisture content = 16.5 kg

λ = Latent heat of vaporization in = 587 kcal/kg

W= Quantity of fuel used = 115 kg.

C = Calorific value of fuel used = 4500 kcal/kg.

$$\eta = \frac{16.5 \times 587 \times (61.25 - 6.00)}{115 \times 4500 \times (100 - 61.25)} \times 100$$

= **26.68%**

Therefore the thermal efficiency of the system was found to be **26.68%**

The moisture content was observed at every 2 hours of interval. The graph was plotted to check the moisture loss with respect to time.

Table 4.6. Average moisture content verses Time for test 2

No.	**Time (hour)**	**Average Moisture**
		Content (% w.b.)
	First day	
1	9.00am	59.24
	11.00am	54.04
	1.00pm	51.46
	3.00pm	48.63
	5.00pm	46.2
	6.30 pm	44.18
2	**Second day**	
	9.00am	43.66
	11.00am	42.15
	1.00pm	40.01
	3.00pm	37.67
	5.00pm	36.52
	6.30pm	34.43
3	**Third day**	
	9.00am	33.29
	11.00 am	27.44

	1.00pm	24.2
	3.00pm	20.17
	5.00pm	15.72
	6.30 pm	12.19
4	**Fourth day**	
	9.00 am	10.59
	11.00am	8.54
	1.00pm	6.64

The Fig 4.10 shows the behavior of moisture content verses time. It was observed that there was a fast removal of moisture from the commodity at the initial hours as shown in graph.

The copra was graded for three grades i.e. white copra brown copra and dusty copra.

Table 4.7. Grade of copra

Trial no 2	**White copra**	**Brown copra**	**Dusty copra**
	52	**34**	**14**

In the second trial there was increase in number of white copra as compared to first trial because of low airflow rate and the low humidity.

4.8.3 Trial third

The sample size for the third trial was 50 coconuts i.e.100 halves. The total weight of the fifty coconuts was 25.20 kg. The initial moisture content was calculated by the AOAC method for 130º C for 1 hour. The 5 gm sample was taken and chopped to calculate the initial moisture content.

Table 4.8 Initial moisture content of the sample trial 3

No	Initial wt of the box with sample (gm)	Final wt. of the box with sample (gm)	Moisture content (%) (w.b.)
1	66.18	63.35	43.40
2	56.59	54.50	58.20

3	56.76	54.97	60.20
4	67.68	65.95	65.40
5	54.76	53.01	65.00
6	65.22	63.49	65.40
		Avg	**59.6**

The trial was carried out to reduce the moisture content from 59.6% w.b. to 6% w.b. The fuel required was 110kg to dry the 50 coconuts. The trial was conducted at the airflow rate of 1.6m^3/min. Total hours required for the drying was 25 hours.

The thermal efficiency of the system was calculated by equation 3.15

$$\eta = \frac{\varphi \times \lambda (M_a - M_f)}{W \times C \times (100 - M_a)} \times 100$$

where,

M_a = Initial moisture content (% wet basis) = 59.6 %

M_f = Final moisture content (% wet basis) = 6%

φ = Quantity of the final dried product at M_f moisture content = 17.2 kg

λ = Latent heat of vaporization in = 587 kcal/kg

W= Quantity of fuel used = 110 kg.

C = Calorific value of fuel used = 4500 kcal/kg.

$$\eta = \frac{17.2 \times 587 \times (59.6 - 6.00)}{110 \times 4500 \times (100 - 59.6)} \times 100$$

= **27.06%**

Therefore the thermal efficiency of the system was found to be **27.06%**

The moisture content was observed at every half hour of interval at initial stage and then the interval was one hour. The graph was plotted to check the moisture loss with respect to time.

Table4.9 Moisture content verses time for test 3

No	Time (hour)	Average moisture content % w.b.
1	**First day**	
	10.3	58.24
	11	56.42
	11.3	54.7
	12	52.5
	12.3	51.1
	1	51.42
	3.3	51.24
	4	49.78
	4.3	49.08
	5	48.33
	5.3	47.72
	6	47.28
2	Second day	
	9.00	46.86
	10	44.5
	11	42.42
	12	39.61
	1	36.7
	3.3	35.94
	4.3	33.16
	5.3	30.94
	6	29.7
3	Third day	
	9	28.05
	10	25.53
	11	23.63
	12	21.88

	1	20.45
	3.3	20.02
	4.3	18.54
	5.3	17.67
	6	16.87
4	Fourth day	
	9	15.7
	10	13.8
	11	12.99
	12	11.63
	1	10.12
	3.3	9.05
	4.3	8.2
	5.3	6.74
	6	5.94

The Fig 4.11 shows the variation of moisture content with time. The total hours required for the drying were 25. The drying was followed at 1.6m^3/min airflow rate.

The quality of copra was evaluated by the visual sense and the grading of copra was done. The grades were white copra, brown copra and dusty copra.

Table 4.10 Grades of copra

Trial no 3	**White copra**	**Brown copra**	**Dusty copra**
	65	24	11

It was observed that this trial required the less hours of drying as compared to other trials. The thermal efficiency of the trial was also higher other than two.

The table given below showed the overall presentation of the quality of the copra for all the trials.

Table 4.11 Grades of copra for all trials

Grade of copra	Trial 1	Trial 2	Trial 3	Average
White copra	48	52	65	55
Brown copra	35	34	24	31
Dusty cups	17	14	11	14

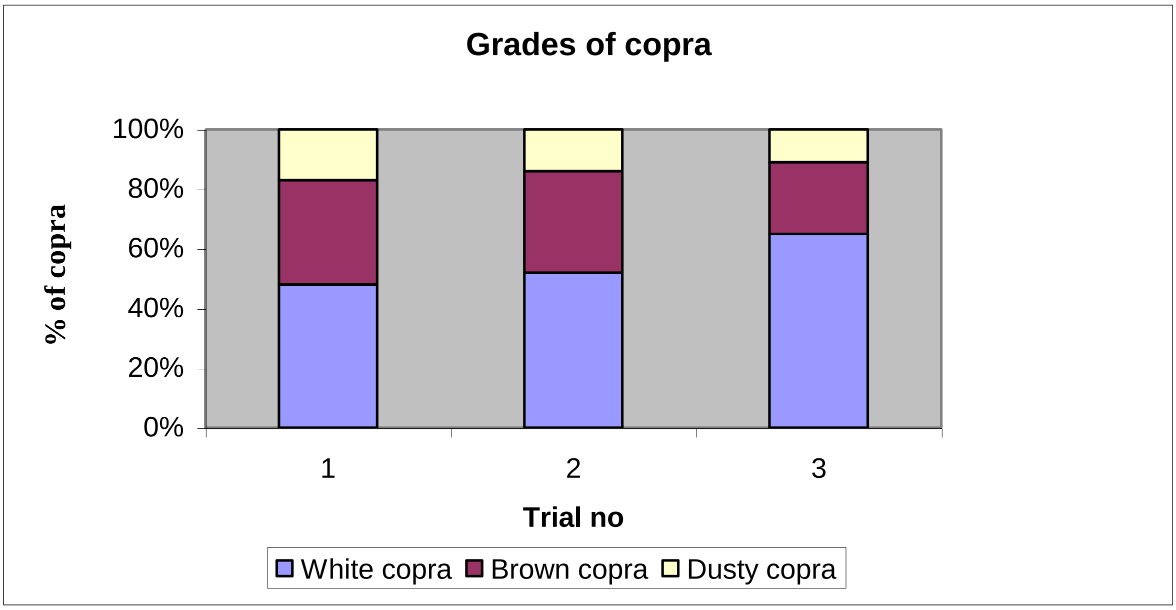

Fig 4.12 Grades of copra

It was observed that on average 55% white copra, 31% brown copra and 14% dusty copra was obtained from the dryer.

4.9. Temperature distribution in the dryer

The maximum temperature attained during trial was 70ºC. The temperatures were recorded in a drying chamber. There were three locations at which temperatures are measured. Temperatures were measured at sensor 1, sensor 2 and exhaust at drying chamber.

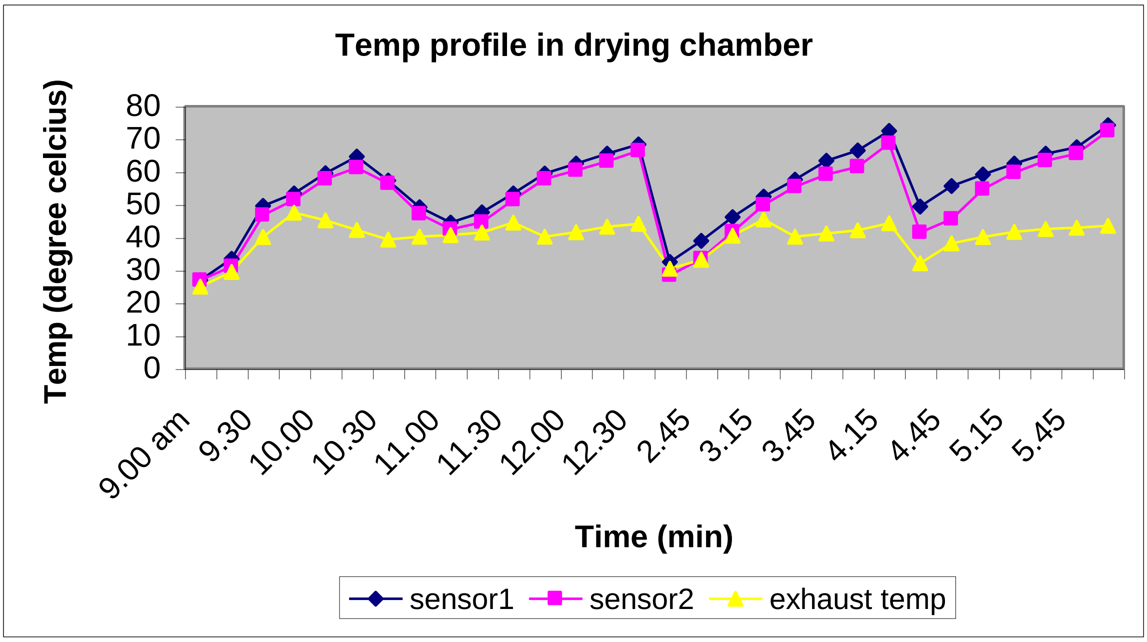

Fig 4.13 Temperature profile in drying chamber

The above graph shows the variation of temperature in drying chamber. The maximum temperature attained in the drying chamber was 75ºC.It was observed that 65ºC was the optimum temperature for the drying above this temperature there was observed the overheating of coconut.

Also there were great variation observed in the drying temperature and the atmospheric temperature. The maximum atmospheric temperature attained during drying was 36ºC. At the maximum temperature it was observed that there was a fast removal of moisture from the commodity. The following graph shows variation of drying temperature and atmospheric temperature.

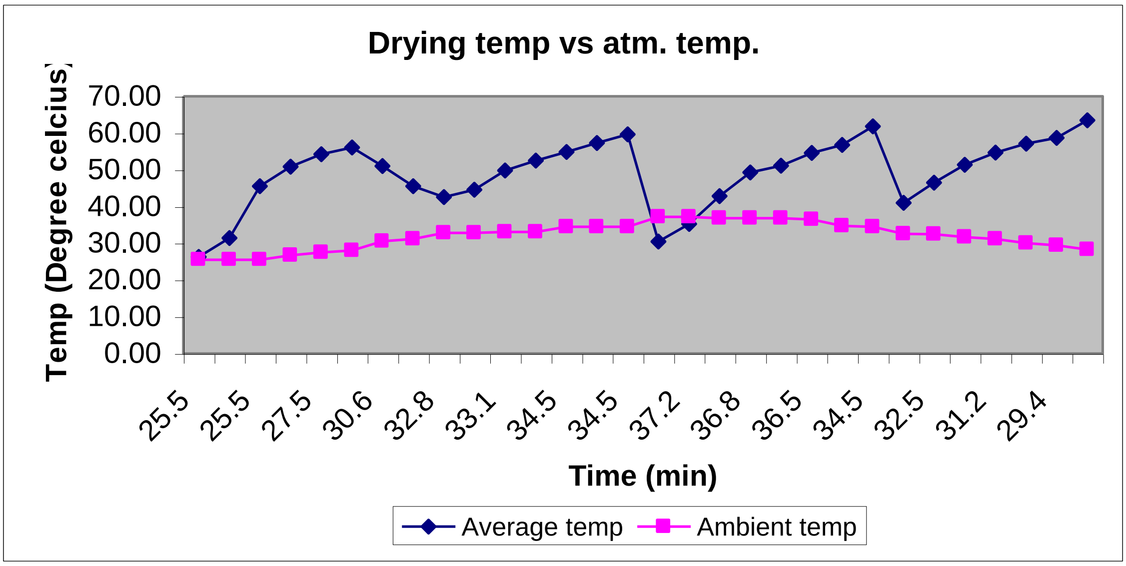

Fig 4.14 Drying temperature verses atmospheric temp.

Thus the temperature was the main factor which affect the drying and moisture removal.

5. SUMMARY AND CONCLUSIONS

Agricultural waste can be used for direct heating in industrial or domestic application. In the conventional practice of coconut processing, which is carried out in Dapoli taluka of Ratnagiri district (Maharashtra) the main source of energy other than sun is the use of agricultural waste as a fuel. Major operations in processing of coconut i.e. copra making include dehusking, splitting and drying. For drying coconut, Processors usually use two methods sun drying and chula drying.

The conventional practices of coconut processing were evaluated in terms of time required for drying, energy required for drying, cost of drying, quality of the final product and problems occur while operation. In the sun drying the major source of the energy was sun while in the chula drying the major source of the energy was coconut waste i.e. coconut rachis, coconut husk etc.

It was found that though the sun drying is the cheap method but it required frequent attention and the quality of the copra was not good as compared to chula drying. The sun drying can be possible only daytime it was the major limitation, which was major reason for the damage of copra. The losses due to insects, birds, animals, dusts and other environmental factors were major. But the chula drying was the continuous process throughout the whole day and night. Any agricultural waste having higher calorific value can be used as a energy source. The losses are minimum and the product quality was better than the sun drying the smell of smoke to the copra is the major limitation.

Considering all these problems a small-scale dryer of combined combustion and drying was designed, fabricated and tested. The parts of the dryer were drying chamber, heating chamber, fuel tray, air distribution pipe, chimney and blower. It was working on the indirect heating and forced convection principle.

From the testing of dryer it was observed that the average thermal efficiency of the dryer was 25.20%. The maximum temperature attained was 65º C.At the temperatures above 75ºC the overheating was observed. The total quantity of fuel require was around 120 kg for total drying from initial moisture content to final moisture content of 6% on wet basis. The dryer was found suitable in rainy season also than conventional methods.

The conclusions drawn from the current study are as follows,

1. The conventional practices of copra making are depending upon the seasonal conditions and the problems like smell of smoke, spoilage to copra was observed in the traditional methods.
2. The hot air was to be as drying medium for drying of coconut, where the primary factor influencing the rate of drying was temperature.
3. The amount of drying air required for 25 kg load of coconut was 900 kg throughout the drying period.
4. The amount of coconut waste required for drying was 120 kg.
5. The optimum airflow rate observed for the drying was 1.6 m^3/min.
6. The optimum temperature was 65ºC
7. The performance of the system was computed in terms of thermal efficiency and the quality of copra. The thermal efficiency of the system was found to be 25.20% where the average percentage of white copra was found to be 55%.
8. The dryer was independent of weather conditions it can be run in a rainy season.
9. There was a variation of 10ºC temperature was observed in the corners and the central region of the drying chamber.

Future suggestions.

1. Any other agricultural waste can be used as a heating source.
2. The construction of the dryer can be made simple.
3. The exhaust air from the drying chamber may be recirculated.
4. The number of tubes may be added in a air distribution pipe for more surface area and fast circulation of air.
5. The baffles may be provided in a drying chamber to avoid the temperature variation.
6. The more trial should be taken for better result interpretation with replications.

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APPENDIX- B

Size and degree of sphericity of coconut.

Coconut no.	Size (Dp) cm.	Degree of sphericity (%)
1	16.60	82.50
2	16.65	87.81
3	17.56	75.88
4	18.02	89.92
5	18.43	95.29
6	16.05	83.33
7	16.74	90.73
8	17.93	80.91
9	19.01	93.18
10	18.21	86.22
11	14.84	89.61
12	15.81	86.72
13	19.19	90.77
14	20.01	88.38
15	16.80	75.74
16	15.78	79.85
17	18.30	79.42
18	13.50	78.48
19	13.52	88.13
20	17.87	84.85
21	16.47	82.80
22	12.58	88.59
23	15.45	82.35
24	15.79	82.06
25	16.68	78.97
26	16.03	83.57
27	15.15	83.42
28	17.55	87.22
29	18.19	84.80
30	15.09	85.93
31	16.76	92.08
32	14.96	89.31
33	17.39	86.17
34	18.99	89.82
35	19.90	89.80
36	16.75	79.38
37	14.78	91.51
38	16.70	91.75
39	16.70	83.91
40	15.68	91.37

41	16.37	85.61
42	15.73	86.66
43	17.97	89.22
44	18.31	88.02
45	18.73	88.76
46	17.65	83.53
47	15.66	81.73
48	19.04	85.84
49	19.38	87.45
50	14.76	91.39

APPENDIX - A

Dimensions of coconut

Coconut no	Length (cm)	Breadth (cm)	Thickness(cm)
1	20.12	15.26	14.92
2	18.96	16.13	15.10
3	23.14	15.50	15.12
4	20.04	17.40	16.80
5	19.34	18.10	17.90
6	19.26	15.14	14.20
7	18.45	16.20	15.70
8	22.16	16.15	16.12
9	20.40	18.51	18.20
10	21.12	17.40	16.45
11	16.56	14.20	13.90
12	18.23	15.40	14.10
13	21.14	18.70	17.90
14	22.64	19.50	18.16
15	22.18	15.16	14.12
16	19.76	24.23	14.00
17	23.04	17.4	15.30
18	17.20	12.14	11.80
19	15.34	13.28	12.14
20	21.06	17.16	15.80
21	19.89	15.20	14.80
22	14.20	12.11	11.60
23	18.76	14.17	13.90
24	19.24	14.50	14.12
25	21.12	15.16	14.50
26	19.18	15.14	14.20
27	18.16	14.20	13.50
28	20.12	16.70	16.10
29	21.45	17.13	16.40
30	17.56	14.15	13.85
31	18.20	16.40	15.80
32	16.75	14.20	14.10
33	20.18	16.18	16.13
34	21.14	18.12	17.90
35	22.16	19.40	18.35
36	21.10	15.16	14.70
37	16.15	14.20	14.10
38	18.20	16.12	15.90
39	19.90	15.50	15.10
40	17.16	15.40	14.60
41	19.12	15.20	15.10

42	18.15	14.90	14.40
43	20.14	17.16	16.80
44	20.80	17.26	17.10
45	21.10	18.10	17.21
46	21.12	16.50	15.80
47	19.16	14.23	14.10
48	22.18	18.16	17.16
49	22.16	18.16	18.10
50	16.15	14.13	14.10

APPENDIX - C

Bulk density of coconut.

Coconut no.	Moisture	Bulk density
	Content (% d.b.)	(Kg/m3)
1	84.36	462.40
2	80.20	455.16
3	82.45	460.38
4	48.56	440.56
5	77.34	453.23
6	59.32	449.44
7	81.74	461.16
8	80.45	457.24
9	59.12	449.14
10	34.26	431.12
11	80.74	461.67
12	76.43	452.73
13	82.32	459.44
14	35.24	437.23
15	54.31	445.38
16	13.65	413.24
17	49.20	441.42
18	65.24	453.14
19	36.76	438.67
20	36.16	436.11
21	44.12	439.00
22	69.30	451.14
23	30.19	430.16
24	66.43	454.22
25	16.30	414.15
26	27.12	425.20
27	82.14	459.25
28	82.44	460.16
29	84.36	462.4
30	75.13	452.73
31	37.17	438.67
32	59.37	449.45
33	77.68	452.14
34	75.15	451.16
35	84.52	464.22
36	79.42	454.17
37	69.32	451.23
38	76.17	453.14
39	55.21	444.38

40	80.53	457.14
41	35.12	434.35
42	49.20	441.22
43	51.77	443.25
44	74.36	456.71
45	71.25	453.25
46	37.14	439.44
47	77.13	454.16
48	45.27	440.40
49	57.17	445.25
50	79.16	457.20

APPENDIX - D

Bulk density of coconut

Coconut no.	Moisture Content (% d.b.)	Bulk density (Kg/m3)
1	80.22	453.1
2	78.14	449.65
3	79.32	457.2
4	44.34	438.16
5	74.30	448.37
6	57.25	445.12
7	77.70	444.34
8	76.37	449.24
9	55.10	446.13
10	32.16	425.37
11	76.35	443.17
12	73.40	447.35
13	78.20	451.16
14	33.43	432.3
15	52.65	440.18
16	10.24	409.24
17	46.26	439.67
18	61.16	447.37
19	33.40	432.34
20	34.18	433.65
21	40.36	438.16
22	65.30	448.22
23	27.16	426.42
24	63.13	447.68
25	13.65	413.24
26	24.30	423.16
27	78.10	449.43
28	76.17	447.14
29	80.47	455.36
30	70.32	445.12
31	33.10	435.36
32	56.17	447.18
33	73.43	440.36
34	71.37	438.67
35	79.18	453.62
36	74.65	443.38
37	63.21	439.5

38	70.25	444.67
39	53.20	441.62
40	74.67	442.18
41	30.17	429.44
42	43.65	441.24
43	46.24	444.53
44	68.36	443.12
45	67.13	441.05
46	35.60	436.57
47	66.27	449.47
48	41.40	438.13
49	52.42	440.35
50	73.12	446.18

APPENDIX-E

Bulk density of dehusked nut (Day wise)

First day			
	Coconut no	**Avg. bulk density**	**Avg. moisture**
		Kg/m3	**Content (% d.b.)**
	1		
	2	**459.66**	**81.65**
	3		
	7		
	8		
	11		
Second day			
	12		
	13		
	27	**458.77**	**80.49**
	28		
	29		
	35		
	45		
Third day			
	33		
	34		
	36	**453.54**	**77.28**
	5		
	50		
	47		
	30		
Fourth day			
	38		
	40		
	44	**453.81**	**71.62**
	22		
	24		
	18		
	37		
Fifth day			
	32		
	39		
	49	**447.17**	**57.41**
	6		
	9		

	15		
Sixth day			
	17		
	21		
	42	440.95	48.02
	43		
	48		
	4		
seventh day			
	46		
	31		
	20	437.41	36.26
	19		
	14		
	41		
Eight day			
	10		
	23		
	26	422.77	28.3
	25		
	16		

APPENDIX - F

True density of dehusked nut

Coconut no.	Moisture content	True density
	(%) d.b.	(kg/m3)
1	78.16	518.62
2	73.41	511.30
3	75.14	514.16
4	42.35	483.36
5	69.43	505.14
6	54.26	497.37
7	74.70	512.60
8	72.20	510.11
9	53.10	495.14
10	29.57	469.68
11	72.47	509.67
12	69.33	506.18
13	74.36	512.13
14	30.31	471.47
15	49.65	489.16
16	9.20	448.37
17	44.35	483.14
18	57.54	497.24
19	30.72	471.55
20	31.27	473.18
21	38.43	478.46
22	61.40	502.14
23	24.14	465.47
24	58.72	498.23
25	10.20	451.16
26	21.42	462.23
27	74.46	512.35
28	72.71	511.61
29	76.20	516.36
30	65.36	504.81
31	31.16	472.80
32	52.43	494.20
33	69.75	506.12
34	67.72	503.17
35	75.16	513.48
36	73.20	510.15
37	58.67	497.76
38	65.42	503.97
39	49.26	488.92

40	71.10	509.20
41	26.72	469.14
42	40.26	479.46
43	41.67	481.22
44	62.46	498.16
45	61.36	495.23
46	31.43	473.36
47	59.21	498.95
48	39.72	479.16
49	49.62	487.20
50	69.12	505.90

APPENDIX -G

True density of dehusked nut

Coconut no.	Moisture content	True density
	(%) d.b.	(kg/m3)
1	75.23	514.20
2	69.42	506.46
3	71.57	507.14
4	40.36	478.47
5	66.72	501.21
6	51.16	492.38
7	71.23	506.84
8	68.56	504.18
9	49.75	486.43
10	26.27	466.20
11	69.46	507.11
12	65.32	498.46
13	70.43	508.10
14	26.47	469.70
15	44.70	482.81
16	8.60	445.20
17	39.70	478.10
18	51.26	492.16
19	25.27	467.27
20	27.42	471.82
21	32.6	474.20
22	58.78	497.73
23	21.6	462.32
24	52.5	493.68
25	9.10	448.16
26	15.14	455.20
27	69.64	505.18
28	68.2	505.10
29	70.54	506.30
30	61.20	494.78
31	27.57	466.32
32	44.36	483.64
33	62.53	496.11
34	61.23	494.10
35	67.42	503.23
36	66.12	503.10
37	51.70	492.80
38	60.47	493.20

39	42.37	483.70
40	65.72	502.80
41	21.46	461.18
42	33.72	476.10
43	35.67	478.81
44	57.42	497.41
45	52.23	494.16
46	26.62	468.81
47	52.47	493.77
48	32.10	474.42
49	42.50	483.30
50	62.72	502.82

APPENDIX -H

Bulk density of husk

Coconut no.	Moisture content	Bulk density
	(%) d.b.	(kg/m3)
1	14.84	114.26
2	11.98	108.25
3	13.36	112.5
4	12.5	110.32
5	10.41	107.21
6	12.17	110.22
7	16.85	115.36
8	15.17	114.11
9	18.5	114.41
10	16.57	111.36
11	11.22	98.26
12	19.4	117.35
13	22.6	119.24
14	13.18	109.26
15	9.25	96.71
16	12.17	110.44
17	13.26	111.32
18	14.41	112.43
19	12.75	109.87
20	11.2	98.23
21	10.45	103.4
22	14.98	112.36
23	17.46	117.82
24	13.21	111.44
25	11.47	99.21
26	21.63	118.16
27	9.78	102.71
28	10.5	104.26
29	11.2	109.21
30	12.14	111.56
31	13.41	114.26
32	14.15	116.42
33	16.26	119.21
34	17.28	121.25
35	10.5	106.61
36	19.38	119.25
37	25.61	121.16
38	22.16	119.32

39	10.39	104.2
40	8.56	97.52
41	11.41	112.21
42	11.6	112.46
43	13.78	110.71
44	13.65	111.4
45	14.11	113.22
46	18.44	118.47
47	19.18	119.23
48	21.12	119.26
49	11.13	112.41
50	17.41	119.11

APPENDIX -I

True density of husk

Coconut no.	Moisture content	True density
	% d.b.	kg/m3
1	21.24	119.71
2	19.76	125.2
3	13.65	121.9
4	25.11	120.25
5	10.65	110.41
6	13.22	115.61
7	14.41	118.81
8	15.21	117.22
9	17.92	118.21
10	15.41	116.62
11	11.15	105.76
12	18.26	119.2
13	21.6	122.16
14	12.77	111.62
15	8.7	101.61
16	11.41	113.18
17	12.2	114.21
18	13.54	116.62
19	11.44	112.32
20	10.9	105.71
21	10.21	109.22
22	13.25	115.37
23	16.85	119.25
24	12.5	116.22
25	11.21	107.41
26	20.42	122.23
27	9.42	107.86
28	10.11	109.21
29	10.52	113.41
30	11.7	117.25
31	12.42	119.55
32	13.96	121.21
33	15.86	124.32
34	16.32	126.31
35	10.41	110.34
36	18.35	122.6
37	24.3	124.41
38	21.1	123.2
39	10.11	113.4
40	8.26	104.2

41	10.27	114.24
42	10.8	114.11
43	11.86	116.21
44	12.82	117.3
45	13.65	119.22
46	17.92	122.53
47	18.8	124.72
48	20.41	125.36
49	10.25	118.8
50	16.38	124.46

APPENDIX - J

Porosity of dehusked nut

Coconut no.	Bulk density	True density	Porosity(%)
	kg/m3	kg/m3	
1	462.40	518.62	10.84
2	455.16	511.30	10.97
3	460.38	514.16	10.45
4	440.56	483.36	8.85
5	453.23	505.14	10.27
6	449.44	497.37	9.63
7	461.16	512.60	10.03
8	457.24	510.11	10.36
9	449.14	495.14	9.29
10	431.12	469.68	8.2
11	461.67	509.67	9.41
12	452.73	506.18	10.55
13	459.44	512.13	10.28
14	437.23	471.47	7.26
15	445.38	489.16	8.95
16	413.24	448.37	7.83
17	441.42	483.14	8.63
18	453.14	497.24	8.86
19	438.67	471.55	6.97
20	436.11	473.18	7.83
21	439.00	478.46	8.24
22	451.14	502.14	10.15
23	430.16	465.47	7.58
24	454.22	498.23	8.83
25	414.15	451.16	8.2
26	425.20	462.23	8.01
27	459.25	512.35	10.36
28	460.16	511.61	10.05
29	462.4	516.36	10.45
30	452.73	504.81	10.31
31	438.67	472.80	7.21
32	449.45	494.20	9.05
33	452.14	506.12	10.66
34	451.16	503.17	10.33
35	464.22	513.48	9.59
36	454.17	510.15	10.97
37	451.23	497.76	9.34
38	453.14	503.97	10.08

39	444.38	488.92	9.1
40	457.14	509.20	10.22
41	434.35	469.14	7.41
42	441.22	479.46	7.97
43	443.25	481.22	7.89
44	456.71	498.16	8.32
45	453.25	495.23	8.47
46	439.44	473.36	7.16
47	454.16	498.95	8.97
48	440.40	479.16	8.08
49	445.25	487.20	8.61
50	457.20	505.90	9.62

APPENDIX – K

Trial no. 1

Initial moisture content= 59.24 Airflow rate = 1.8m^3/min.

First day			Second day		
Initial wt.	weight loss	Moisture content	Time	wt.loss	Moisture %
343.78	326.48	53.94	9.00am	292.28	42.74
228.21	217.74	54.43		201.79	46.72
201.74	188.45	52.18		172.43	43.19
221.14	209.72	53.79		188.67	43.06
259.35	252.15	56.98		223.1	43.93
141.34	132.94	52.92		119.79	42.33
		Avg. 54.04			Avg 43.66
Wt. loss	Moisture%			wt.loss	Moisture
319.38	51.71		11.00am	286.77	40.81
212.58	52			199.51	45.57
186.17	50.95			169.53	41.47
203.72	50.84			185.74	41.48
245.21	53.54			220.11	42.57
128.84	49.73			118.26	41.03
	Avg 51.46				avg 42.15
wt.loss	Moisture%			wt.loss	Moisture
309.63	48.56		1.00pm	285.24	39.21
208.53	50.05			189.38	41.26
182.02	48.67			163.68	39.78
198.38	48.14			178.35	40.2
236.09	49.67			216.63	40.15
125.04	46.69			114.72	39.49
	Avg 48.63				Avg40.01
wt.loss	Moisture%			wt.loss	Moisture
302.44	46.21		3.00pm	280.13	38.1
204.94	48.29			186.36	37.87
178.07	46.45			159.7	37.1
193.24	45.48			175.2	37.65
229.25	46.68			210.3	37.4
121.94	44.14			112.3	37.9
	Avg. 46.20				Avg37.67
wt.loss	Moisture%			wt.loss	moisture
294.6	43.54		5.00pm	277.16	36.12
202.14	46.9			183.78	36.5
173.96	44.08			157.12	37.1
189.64	43.58			174.62	36.2

224.48	44.55			206.18	36.45
119.91	42.44			111.18	36.78
	avg. 44.18				Avg 36.52
				wt.loss	moisture
			6.30pm	274.2	34.1
				181.16	35.11
				155.43	34.56
				173.1	34.49
				204.87	34.56
				110.2	33.8
					Avg.34.43

	Third day				Fourth day	
Time	wt.loss	moisture		Time	wt.loss	moisture
9.00am	273.14	35.81		9.00am	220.17	10.58
	179.98	34.71			141.23	11.1
	153.4	30.95			124.2	10.12
	171.72	33.31			138.67	10.78
	198.78	31.83			159.9	11.1
	109.64	33.16			86.12	9.9
		Avg. 33.29				Avg 10.59
	wt.loss	moisture			wt.loss	moisture
11.00am	267.18	33.57		11.00am	215.78	11.56
	168.64	27.98			140.21	8.84
	148.72	27.8			122.56	7.93
	162.2	27.44			134.2	7.97
	186.18	25.06			157.65	8.04
	99.36	22.81			85.1	6.93
		avg. 27.44				Avg. 8.54
	wt.loss	moisture			wt.loss	moisture
1.00 pm	255.45	29.32		1.00pm	206.63	7.13
	159.25	23.5			138.25	7.42
	143.7	24.97			120.58	6.33
	158.45	24.56			132.56	6.74
	182.5	23.4			155.2	6.46
	96.2	19.45			84.12	5.76
		avg. 24.20				Avg. 6.64
	wt.loss	moisture				
3.00pm	249.18	26.34				
	152.32	17.26				
	139.41	21.12				
	151.68	20.5				
	176.5	19.57				
	93.23	16.23				

		Avg. 20.17				
	wt.loss	moisture				
5.00pm	235.7	20.62				
	148.32	14.56				
	131.72	15.28				
	147.2	17.45				
	168.32	14.71				
	89.23	11.74				
		Avg 15.72				
	wt.loss	moisture				
6.30pm	229.2	17.78				
	142.62	10.56				
	126.32	11				
	141.73	13.59				
	163.42	11.71				
	86.45	8.52				
		Avg. 12.19				

APPENDIX – L

Trial no. 2

Initial moisture content = 61.25 %   Air flow rate = 1.1m^3/min.

First day				Second day		
Time	Initial wt.	Weight loss	Moisture	Time	Wt.loss	Moisture %
			Content %			
9.00am	155.04	149.25	57.37	9.00am	117.26	36.48
to 11am	196.53	189.45	57.51		149.26	36.93
	192.28	185.7	57.68		144.56	35.73
	184.58	178.5	57.84		139.65	35.92
	231.1	222.4	57.33		177.9	38.36
	261.47	252.8	57.82		196.2	35.2
			Avg. 57.59			Avg 36.43
	Wt. loss	Moisture%			Wt.loss	Moisture
1.00 pm	139.8	54.49		11.00am	112.46	32.21
	177.5	54.41			142.53	32.2
	175.2	55.25			138.46	31.32
	167.2	54.49			133.8	31.54
	208.5	54.58			170.8	34.2
	237.8	54.94			187.26	30.42
		Avg 54.69				avg 31.98
	Wt.loss	Moisture%			wt.loss	Moisture
3.00pm	133.52	49.78		1.00pm	108.5	28.56
	169.26	49.64			137.2	28.41
	168.15	51.27			134.25	28.18
	159.4	49.46			129.56	28.26
	198.56	49.57			162.45	29.05
	226.16	49.79			182.5	27.81
		Avg 49.91				Avg28.37
	Wt.loss	Moisture%			wt.loss	Moisture
5.00pm	128.25	45.67		3.00pm	106.1	26.29
	161.2	44.79			135.12	26.87
	159.85	46.07			131.8	26.32
	151.45	44.21			126.5	25.84
	191.32	45.78			158.46	26.53
	218.4	46.23			179.2	25.96
		Avg. 45.45				Avg26.30

	Wt.loss	Moisture%			wt.loss	moisture
6.30pm	121.4	40.02		5.00pm	104.12	24.38
	155.4	41.05			131.8	24.35
	150.23	39.66			128.84	24.02
	144.85	39.65			124.1	23.89
	185.24	42.49			155.7	24.75
	209.56	42.01			177.12	24.78
		avg. 40.81				Avg 24.36
					Wt.loss	Moisture
				6.30pm	102.2	22.5
					129.4	21.56
					125.65	22.87
					121.3	21.2
					152.45	20.8
					173.8	22.1
						Avg.21.83
Third day				Fourth day		
Time	Wt.loss	Moisture		Wt.loss		Moisture
9.00am	99.95	19.81		84.34		9.1
	126.15	20.45		106.8		8.56
	121.45	19.1		102.45		8.47
	117.65	21.1		91.82		8.9
	149.56	20.46		128.65		9.23
	169.2	18.89		149.9		8.7
		Avg. 19.96				Avg. 8.82
	Wt.loss	Moisture		Wt.loss		Moisture
11.00am	96.59	16.65		80.34		7.12
	123.45	17.1		101.5		6.9
	118.54	16.56		97.56		7.17
	112.9	17.2		82.53		6.2
	146.2	17.85		122.9		6.98
	165.43	16.43		141.9		6.14
		avg. 16.96				Avg 6.75
	Wt.loss	Moisture				
1.00pm	94.25	15.2				
	121.79	15.13				
	116.5	14.9				
	111.2	15.2				
	144.12	14.67				
	163.2	14.34				
		Avg. 14.90				
3.00pm	93.2	14.5				

	119.3	15.12			
	115.4	14.25			
	109.87	14.78			
	141.47	15.43			
	161.23	14.3			
		Avg. 14.73			
	Wt.loss	Moisture			
5.00pm	90.1	13.1			
	115.67	12.89			
	110.35	13.76			
	102.59	12.9			
	138.2	14.71			
	158.45	11.98			
		Avg 13.22			
	wt.loss	moisture			
6.30pm	87.2	11.78			
	110.49	10.56			
	106.45	11.9			
	99.34	12.1			
	132.89	11.71			
	151.23	10.2			
		Avg. 12.87			

APPENDIX –M

Trial no. 3

Initial moisture content 59.6% Airflow rate =1.6m^3/min.

First day				Second day		
Time	Initial wt.	Wt. loss	Moisture	Time	Wt.loss	Moisture
			Content			
10.00 a.m	170.23	168.25	58.44	9.00am	148.3	45.81
to 10.30 am	164.48	161.54	57.82		143.7	46.13
	156.14	153.7	58.04		134.1	44.44
	252.65	250.12	58.59		227.1	48.92
	170.09	167.34	57.99		150.1	47.14
	194.53	192.54	58.58		174.2	48.73
		Avg.	58.24333		avg	46.86
	Wt. loss	Moisture%			Wt.loss	Moisture
11.00am	164.2	55.98		10.00am	145.6	43.98
	158.26	55.75			139.45	43.17
	150.54	55.95			131.2	42.27
	247.24	57.43			224.5	47.75
	165.1	56.64			144.43	43.36
	189.1	56.77			170.34	46.51
	Avg.	56.42			avg	44.5
	Wt.loss	Moisture%			Wt.loss	Moisture
11.30 a.m	160.4	53.66		11.00pm	141.79	41.36
	155.45	53.97			136.65	41.16
	147.23	53.75			128.9	40.51
	244.56	56.34			220.78	46.09
	162.7	55.18			140.2	40.43
	186.34	55.31			167.8	45.01
	Avg.	54.7			avg	42.42
	Wt.loss	Moisture%			Wt.loss	Moisture
12.am	157.23	51.68		12.00pm	138.5	39.03
	151.23	51.25			132.23	37.92
	143.7	51.35			124.5	36.73
	240.23	54.56			216.7	44.24
	158.23	52.43			136.43	37.74
	183.45	53.75			162.78	42.01
	Avg.	52.5			Avg	39.61
	Wt.loss	Moisture%			Wt.loss	Moisture
1.oopm	155.5	50.57		1.00pm	134.5	36.14
	150.2	50.56			128.9	35.4
	141.2	49.61			121.3	34.15

	238.56	53.86			206.54	39.55
	156.4	51.27			132.65	34.96
	181.5	52.68			159.56	40.03
	Avg.	51.42			Avg	36.705
3.30 p.m.	Wt.loss	Moisture%			Wt.loss	Moisture
	155.2	50.37		3.30pm	133.75	35.58
	150.12	50.5			127.56	34.36
	140.8	49.32			120.56	33.53
	238.1	53.66			205.23	38.91
	156.12	51.09			131.25	33.9
	181.2	52.51			158.56	39.4
	Avg.	51.24			Avg	35.94
4.00 p.m.	Wt.loss	Moisture%		4.30 pm	Wt loss	Moisture
	153.1	49.01			129.56	32.44
	148.2	49.22			122.59	30.46
	138.12	47.41			116.45	30.12
	234.43	52.11			201.45	37.06
	154.67	50.16			128.56	31.85
	178.12	50.81			154.89	37.08
	Avg.	49.78				33.16
4.30 p.m.	Wt.loss	Moisture%		5.30 pm	Wt loss	Moisture
	152.25	48.45			127.67	30.98
	147.4	48.68			119.56	27.98
	137.5	46.96			114.2	28.18
	231.5	50.86			197.6	35.14
	153.4	49.33			124.5	28.69
	177.1	50.23			151.23	34.71
	Avg.	49.08			avg	30.94
5.00 p.m.	Wt.loss	Moisture%		6.00pm	Wt.loss	Moisture
	151.1	47.69			126.25	29.86
	146.2	47.86			117.56	26.3
	136.43	46.18			113.26	27.35
	229.23	49.87			195.56	34.1
	152.3	48.61			122.45	26.64
	176.34	49.8			150.1	33.96
	Avg.	48.33			avg	29.7
5.30 p.m.	Wt loss	Moisture %				
	150.34	47.18				
	145.3	47.24				
	135.8	45.71				
	228.1	49.37				
	151.4	48.01				
	175.59	49.37				
	Avg.	47.72				
6.00 p.m.	Wt.loss	Moisture%				

	149.2	46.42				
	144.39	46.61				
	134.78	44.95				
	227.54	49.12				
	150.67	47.52				
	174.78	48.9				
	Avg.	47.28				

	Third day			Fourth day	
Time	Wt.loss	Moisture	Time	Wt.loss	Moisture
9.00am	121.56	26.14	9.00am	108.5	14.81
	114.3	23.52		104.89	14.2
	109.6	24.11		99.96	14.91
	190.25	31.38		165.21	17.36
	117.15	29.77		100.1	14.88
	149.25	33.39		127.89	18.09
	avg	28.05		avg	15.7
	Wt.loss	Moisture		Wt.loss	Moisture
10.00am	119.54	24.47	10.00am	106.6	13.05
	112.67	22.09		103.2	12.58
	107.78	22.44		98.14	13.08
	182.9	27.51		162.68	15.82
	113.9	26.99		98.1	12.88
	143.78	29.72		124.5	15.43
	avg	25.53		avg	13.8
	Wt.loss	Moisture	11.00pm	Wt loss	Moisture
11.00am	117.89	23.08		104.89	11.44
	110.56	20.21		102.56	11.95
	106.23	21		97.89	12.82
	179.32	25.55		161.58	15.14
	110.25	24.49		97.14	11.9
	140.58	27.49		123.58	14.69
	avg	23.63		avg	12.99
12am	Wt loss	Moisture	12.00 pm	Wt loss	Moisture
	115.89	21.38		102.56	9.21
	109.15	18.19		100.89	10.32
	105.12	19.95		96.32	11.21
	177.14	24.33		159.58	13.9
	108.56	22.95		96.56	11.3
	136.39	24.5		122.54	13.84
	avg	21.88		avg	11.63
	Wt.loss	Moisture	1.00 pm	Wt loss	Moisture
1.00pm	113.84	19.61		101.23	7.91
	108.32	17.42		99.23	8.67

	104.12	18.99		95.45	10.3
	174.96	23.09		158.12	12.98
	105.58	20.20		94.56	9.22
	134.89	23.40		119.89	11.67
	avg	20.45		avg	10.12
	Wt.loss	Moisture	3.30 pm	wt loss	Moisture
3.30pm	113.15	19.00		100.98	7.66
	108.1	17.21		98.96	8.39
	103.96	18.83		94.12	8.9
	174.2	22.65		154.89	10.93
	104.89	19.54		93.56	8.16
	134.25	22.92		118.25	10.3
	avg	20.02		avg	9.05
4.30pm	Wt loss	Moisture	4.30 pm	Wt loss	Moisture
	111.23	17.30		100.1	6.7
	107.56	16.71		98.1	7.52
	102.36	17.29		93.98	8.75
	171.89	21.32		153.1	9.77
	103.1	17.83		93.1	7.66
	131.45	20.83		117.1	9.32
	avg	18.54		Avg	8.2
5.30 pm	Wt loss	Moisture	5.30pm	Wt.loss	Moisture
	110.25	16.41		99.98	6.58
	106.12	15.37		97.1	6.5
	101.96	16.89		91.75	6.37
	170.65	20.59		149.55	7.45
	102.56	17.30		92.02	6.49
	129.65	19.46		114.45	7.05
	avg	17.67		Avg	6.74
6.00 pm	Wt loss	Moisture	6.00pm	Wt.loss	Moisture
	109.69	15.90		99.1	5.69
	105.98	15.23		96.68	6.06
	101.12	16.06		91.12	5.68
	166.98	18.43		148.2	6.54
	101.96	16.71		91.56	5.9
	128.98	18.94		113.1	5.8
	avg	16.87		Avg	5.94

Appendix - N