TESTING AND DEVELOPMENT OF CAET DAPOLI DEVELOPED COPRA DRYER USING COCONUT HUSK AS A FUEL

A Thesis submitted to the

DR.BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH

DAPOLI – 415712

Maharashtra State (India)

In the partial fulfillment of the requirements for the degree

Of

MASTER OF TECHNOLOGY

(AGRICULTURAL ENGINEERING)

In

AGRICULTURAL PROCESS ENGINEERING

By

Sujata Krishna Sawant

B.Tech. (Agril. Engg.)

By
Sujata Krishna Sawant

DEPARTMENT OF AGRICULTURAL PROCESS ENGINEERING
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2010

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

University or Institute

for a Degree or

Diploma.

Place: CAET, Dapoli **(Miss Sujata Krishna Sawant)**

Dated: / /2009

Place: CAET**,** Dapoli **(N. J. Thakor)**

Date: / / 2009 Research Guide

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CERTIFICATE

This is to certify that the thesis entitled, **"TESTING AND DEVELOPMENT OF CAET DAPOLI DEVELOPED COPRA DRYER USING COCONUT HUSK AS A FUEL"** submitted to the Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (Maharashtra State) in the partial fulfillment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Agricultural Process Engineering,** embodies the record of a piece of bonafied research work carried out by **Miss. Sawant Sujata Krishna** under my guidance and supervision. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

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

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Dated: / /2009.

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Place : CAET, Dapoli

Date : / /2009 **Miss Sujata Krishna Sawant**

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LIST OF SYMBOLS

Symbols	Description
et al.	And other
i.e.	That is
m	Meter
m^2	Square meter
m^3	Cubic meter
g	Gram
kg	Kilogram
hr	Hour
Kg/m^3	Kilogram per cubic meter
Kg/m^2	Kilogram per square meter
%	Per cent
^oC	Degree Celsius
kcal	Kilocalorie
Kcal/hr	Kilocalorie per hour
W	Watt
cm	Centimeter
mm	Millimeter
Pa	Pascal
Hp	Horse power
ha	Hectare

LIST OF ABBREVIATIONS

Abbreviations	**Meanings**
atm.	Atmosphere
A_d	Area of drying chamber
a_c	Cross sectional area of chimney
B	Breadth
C	Velocity of air
C_{pc}	Specific heat of coconut husk
C_{pw}	Specific heat of water
C_n	Calorific value of fuel
C.O.P.	Coeffient of performance
d.b.	Dry basis
F	Fuel rate
g	Acceleration due to gravity
G	Rate of air supply
G.I.	Galvanized iron sheet
H	Height of chimney
H.U.F.	Heat utilization factor
K	Thermal conductivity
L	Length
m.c.	Moisture content
M_i	Initial moisture content of the sample
M_f	Final moisture content of the sample
N	Nitrogen
θ	Drying period of coconut
P_d	Pressure drop in dryer
P_S	Static pressure drop
P_L	Pressure loss in conveying pipes

P_1	Actual draft of chimney
Q	Heat loss
Q_a	Airflow rate
q_e	Rate of exit air
q_a	Total heat required
R	Drying rate
Rha	Atmospheric relative humidity
R.H.	Relative humidity
t_1	Dry bulb temperature of drying air
t_0	Dry bulb temperature of ambient air
t_2	Dry bulb temperature of exhaust air
t_d	Total drying time
t_{ci}	Initial temperature of coconut
t_{cf}	Final temperature of coconut
T_i	Inside temp. of heating chamber
T_o	Outside temp. of heating chamber
t_h	Thickness of bed
Td	Average temperature in drying chamber
Te	Exhaust air temperature
Ta	Ambient air temperature
T_{UL}	Upper tray left side temperature
T_{UR}	Upper tray right side temperature
T_{BL}	Bottom tray left side temperature
T_{BR}	Bottom tray right side temperature
T_U	Average upper tray temperature
T_B	Average bottom tray temperature
V_1	Humid volume
V2	ml of HCl used in determination
V3	ml of HCl used in blank

W_w	Moisture removed
W_g	Initial mass of the wet coconut
w.b.	Wet basis
x	Thickness of material
X_{id}	Initial moisture content of coconut, (d.b.) in fraction
X_{fd}	Final moisture content of coconut, (d.b.) in fraction
CAET	College of Agricultural Engineering and Technology

ABSTRACT

TESTING AND DEVELOPMENT OF CAET DAPOLI DEVELOPED COPRA DRYER USING COCONUT HUSK AS FUEL.

by

SAWANT SUJATA KRISHNA

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2009

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Copra drying in Konkan region is practiced largely through sun drying and chula drying which has its own demerits while use of mechanical copra dryer is very scarce. Konkan region has more than 100 rainy days of the year with average rainfall of 3000 mm (40-140 mm/hr) and sun drying during rainy season is for coconuts harvested in rainy season is impossible. There is need to have a simple mechanical batch type copra dryer suited to the requirements of konkan farmers having small land holding. The department of Agricultural Process Engineering of Dr, BSKKV Dapoli developed batch type indirect force convection copra dryer through research studies of PG student.

The present study is the investigation carried out on the performance testing of CAET developed copra dryer and improvement and testing of the modified CAET copra dryer. During testing it is observed that CAET developed copra dryer can be completed drying operation by using 120 kg coconuts husk as a fuel to dry 8 kg batch of coconut halves. The CAET developed copra dryer removed 134 g moisture per hour from 8 kg coconuts halves. Average 30 kg fuel consumed to

remove 1 kg of water from coconut halves from initial moisture content 50 per cent to 6 percent final moisture content. Also convection of heat from heating chamber to drying chamber through one single pipe limits the utilization of available heat energy in the heating chamber for drying of coconut halves. It is observed that 40-45 per cent heat loss (1500 W) found from heating chamber walls due to lack of insulation. Total space required for dryer unit is 3 m^2, which create difficulty in movement from one place to another.

Modified CAET copra dryer relatively require less space (0.81 m^2) and dryer provide with Castor wheel for easy movement from one place to another. It is observed that heat loss through heating chamber walls 150 W and saving in heat energy of 10 times (1000 W) over the CAET developed copra dryer. Drying operation with modified CAET copra dryer can be completed by using a very less amount of fuel (Coconut husk) of 20 kg to dry 16 kg batch of coconut halves and saving in fuel by 6 times over the CAET developed copra dryer. The modified CAET copra dryer removed 267 g moisture per hour from 16 kg coconuts halves. Average 4 kg fuel consumed to remove 1 kg of water from coconut halves from initial moisture content 50 per cent to 6 per cent final moisture content. The drying capacity (16 kg coconut halves copra / batch) of modified CAET copra dryer is two times higher than the CAET developed copra dryer. In the CAET developed copra dryer the use of blower is necessary to convey the heat from heating chamber to drying chamber however heat can be convey from heating chamber to drying chamber in the modified CAET copra dryer without using the blower or in the absence of blower. Modified CAET copra dryer can be used by indirect natural convection batch type method. Percentage of white copra found 72 per cent after drying operation of modified CAET copra dryer and improving 15 per cent quality of copra over the CAET copra dryer. Modified CAET copra dryer is providing efficient drying and has large drying capacity and potential fuel saving ability also use with natural convection indirect batch type method.

I. INTRODUCTION

The coconut palm (Cocus nucifera L.) is most important horticulture crop. It is an exclusive means of livehood to millions of small and marginal farmers in India. It is a crop for food, oil, fibre, beverage, timber and fuel. It also provides a variety of raw material for production of an array of products of commercial importance. Coconut tree is ranked among one of the 10 most useful trees of the world (Anonymous, 2005-a).

The world production of coconut is about 55 million tons. In India, coconut is cultivated in about 1.9 million ha mainly in southern states of Kerala, Karnataka, Tamilnadu, Andhra Pradesh and Maharashtra (Thampan 1998). 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 (Nagwekar *et.al* 2003). In the year 2006-07 India is highest coconut production country in the world, it is about 15840 million nut annually (Anonymous, 2008).

The fruit of coconut is considered as the reservoir of food and beverage. The mature coconut kernel is the rich source of protein, fat, carbohydrate and dietary fiber. Coconut oil, a medium chain saturated fatty acid rich in lauric acid is ideal source of dietary fat. The role of coconut in providing food security with links to poverty alleviation, policy planning, control of malnutrition, improving health for millions of people in the country is considered important (Mathew, 2008).

Fresh coconut meat contains 50-55 % moisture. Drying must be carried out within 4 hrs of splitting since coconut meat deteriorates very rapidly due to growth of mould & bacteria, the most harmful of which is the yellow green mould called *Aspergillus flavus* and other aflatoxin related moulds. The greasy surface continues to develop within 24 hrs. (Nampoorthiri *et.al*, 1999). Microbial activity is reported to be more when moisture content is above 20 percent (Nampoorthiri *et.al*, 1999). So in this case drying is an important unit operation. In order to make copra edible and useful it is necessary to dry it within the shortest possible period to avoid microbial activity. Hence to encourage future commercial applications to increase the income from coconut through trade in modern value added products coconut needs drying. The common methods of copra drying available in the country are sun drying, kiln drying, direct or semi-direct drying and hot air drying.

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 milling and edible.

Edible copra is made in the form of cups and balls. Ball copra is obtained from mature unhusked nuts stored in the shade for 8 to 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. Milling copra is mostly in the form of cups and to a very small extent in the form of chips. The dried coconut (copra) has a great market value. It is also used in the manufacture of cakes, pastries and chocolates.

Copra drying in Konkan region is practiced largely through sun drying and chula drying which has its own demerits while used of mechanical copra dryer in Konkan region is very scared due to undeveloped mechanization. Konkan region has more than 100 days of rainy days of the year; it has average rainfall intensity 40-140mm/hr during which sun drying is simply impossible. There is a need to have a simple mechanical indirect batch type dryer suited to the requirement of Konkan farmers. So Batch type indirect forced convection copra dryer was developed through M-Tech student (Sane, 2006) in the department of APE of Dr, BSKKV's Dapoli. It is rigorous testing & modification if necessary needs to be undertaken to make the dryer useful for Konkan farmers.

Therefore the present study was undertaken with the following objectives;

1) To test the CAET Dapoli developed copra dryer.
2) To modify the CAET Dapoli developed copra dryer based on test results.
3) To test and evaluate the modified CAET Dapoli copra dryer.

II. REVIEW OF LITERATURE

This chapter deals with brief review of the literature pertaining to various parameters involved in the importance of coconut and process of copra making. 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 various types of dryers for copra and quality characteristics of copra are reviewed.

2.1 Coconut 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.

Singh and 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.

III. 2.2 Food value of coconut and copra

Anonymous (2005-b) reported that 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.

Onifade A.K. and Y.A. Jeff-Agboola (2003) reported that Coconut 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.

Mathew M. Thomas (2008) Coconut contains almost all essential vitamins and minerals, which are necessary for health. Coconut and coconut products play a vital role in uplifting the nutritional status along with health protection of the population. The fruit of coconut is considered as the reservoir of food and beverage. The mature coconut kernel is the rich source of protein, fat, carbohydrate and dietary fiber. Coconut oil, a medium chain saturated fatty acid rich in lauric acid is ideal source of dietary fat. The role of coconut in providing food security with links to poverty alleviation, policy planning, control of malnutrition, improving health for millions of people in the country is considered important.

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.

IV.2.3. Copra drying

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. Fresh coconut meat contains 50-55 % moisture. Drying must be carried out within 4 hrs of splitting since coconut meat deteriorates very rapidly due to growth of mould & bacteria. So in this case drying is an important unit operation. In order make copra edible & useful it is necessary to dry it within the shortest possible duration to avoid microbial activity. So to encourage future commercial applications to increase the income from coconut through trade in modern value added products coconut needs drying.

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.

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.

Muller and 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.

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 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.

Bosco and Singh (2001) developed agricultural waste based dryers. The dryers of various capacities viz, 100, 400, 1000, and 3000 coconut/batch using agril. wastes as fuel are available. These dryers comprises of drying chamber, plenum chamber, burning-cum- heat exchange unit and chimney with regulators. These dryers are constructed from locally available materials such as asbestos sheet, GI sheet, MS angles, flats and wire mesh. For 3000 coconuts capacity dryer, bricks are used to construct sidewalls. The produce to be dried is kept in the drying chamber. As the fuel is burnt in the burning chamber, the flue gases heat the GI sheet surface by conduction. Generally, the drying is carried out for four days with the overnight breaks till the moisture content of copra reaches 6 per cent for safe storage. The actual time taken for drying was found to about 36 hours.

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.

Satter (2003) developed a portable copra dryer. The overall dimensions of the dryer are 1800 mm long x 740 mm wide x 1250 mm high. It is a clean hot air dryer. It consists of a fire tube (Combustion chamber) fabricated from a steel tube with dimensions 300mm diameter, 3mm wall thickness and 1800mm length. Copra husks and shells are burnt at one end of the tube. Combustion gases exit through a small chimney located at the other end. The amount of fresh air intake into the tube can be regulated to control the rate of burning. The fire tube is located within a frame welded from rectangular profiles. The frame is covered by plywood sheets forming four vertical walls. There is a provision for placing in and taking out copra trays from the drying chamber. Copra tray is made of wire mesh welded to a metal frame and placed at intervals within the drying chamber. The entire space from the bottom of the fire tube to top tray forms the drying chamber. The air vent around the fire tube for entry of fresh air into the drying chamber can be regulated. A wire mesh screen is also placed about 150mm above the fire tube in order to create turbulence in the hot air rising from the tube. Turbulence ensures greater uniformity of temperature within the drying chamber Dryer is based on indirect heating, and suitable for any woody mass fuels to be used in the fire tube. It is clean hot air dryer, so no fouling occurs from the combustion gases. In the dryer, air vent is around the fire tube, so practically no heat is lost to the ground. Temperature level within the drying chamber can be controlled by regulating the air vent. The drying cycle time is a direct function of temperature; it is thus possible to shorten the cycle time by proper control of temperature. There is also a provision for creating greater turbulence in the hot air to obtain uniformity of temperature within the drying chamber. The dryer operation is simple. A certain amount of husk/shell is placed on a grate at the firing end of the fire tube and then lighted. Once the desired temperature is reached, copra trays can be placed on shelves in the drying chamber through doors on one of the vertical walls. Thereafter it is necessary to recharge the fire tube to maintain a steady burning rate. Also, air vent is to be adjusted to obtain the desired temperature until the drying is complete. There is very little need for maintenance except removing the ash and cleaning the fire tube at regular intervals.

Sane (2006) It is batch type indirect heating forced convection dryer, which consists following main components, are Drying chamber, heating chamber, air distribution unit, chimney. The drying chamber and heating chamber was fabricated by using mild steel (M.S.). The drying chamber and exhaust port was built in one section as one unit. Heating chamber was a separate unit, which was having fuel tray. The fuel tray was fitted below the air distribution pipe in the heating chamber. Chimney was provided to heating chamber for escape of smoke and air indirectly heated above the fuel box was convey to the drying chamber through 75 mm diameter of pipe with the help of blower having 0.70Hp motor. The asbestos sheet was used as an insulating material for heating chamber.

Madhavan and Bosco (2004) developed a solar tunnel dryer. In this dryer fresh coconuts are dried from m.c. 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.

Anonymous (2007) in the modern drier coconut cups can be converted into copra in 16-32 hours even during the rainy season. In these driers the heat generated by burning coconut shell and other farm wastes is used to dry raw coconut cups into copra. Since smoke does not come into contact with coconut cups or copra and the process of drying starts immediately after splitting the nuts, the copra produced is of high quality which fetches premium price than the ordinary sun dried or kiln dried copra for which a minimum 8-9 days are required to bring down the moisture to the required level. In the small drier of batch type (natural drought type), coconut husks and other agriculture wastes are used as fuel. Its capacity ranges between 400-3000 nuts per day and it takes 36-48 hours to process coconuts into copra. There are also big dryers of induced drought type with capacity ranging between 10,000 and 25,000 nuts and even beyond, to dry coconuts into copra or dry copra further to bring down the moisture level to the required level. Coconut shells are used as fuel in such dryers.

2.5. 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 temperature 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 g 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 fired 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 up to 65 % of oil of good quality as the drying is done under hygienic environment.

Eutiquio and E.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.

2.6. Copra Quality

Thampan (1998) 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. Other than the moisture content, the quality of copra is influenced by several other factors of which rubberiness, case hardening and charring are decisive.

Guarte and Miihlbauer (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/min. 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.

III. MATERIAL AND METHODS

This chapter deals with materials and methods used for testing and development of CAET Dapoli developed copra dryer. In the first section the detailed study of CAET Dapoli developed copra dryer were described. The testing of CAET Dapoli developed copra dryer was done. The second section deals with the modification of CAET Dapoli developed copra dryer were done based on tests results. The last section deals the fabrication of the modified CAET Dapoli copra dryer and its evaluation.

3.1 The CAET Dapoli developed copra dryer

CAET Dapoli copra dryer was developed in 2006 at the department of APE of Dr. BSKKV Dapoli (Sane, 2006). It is batch type indirect heating forced convection dryer, which consists following main components, are:

1) Drying chamber
2) Heating chamber
3) Air distribution unit
4) Chimney

The drying chamber and heating chamber was fabricated by using mild steel (M.S.). The drying chamber and exhaust port was built in one section as one unit. Heating chamber was a separate unit, which was having fuel tray. The fuel tray was fitted below the air distribution pipe in the heating chamber. Chimney was provided to heating chamber for escape of smoke and air indirectly heated above the fuel box was convey to the drying chamber through 75 mm diameter of pipe with the help of blower having 0.70Hp motor. The asbestos sheet was used as an insulating material for heating chamber. The overall view of CAET Dapoli developed copra dryer is shown in Fig. 3.1

3.2 Testing of CAET Dapoli copra dryer

The primary testing of the CAET Dapoli developed copra dryer was under taken after the fabrication through M-Tech student (Sane, 2006). It was observed that the maximum temperature recorded in the drying chamber due to heating was 70^0C. 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 drying with avg. 120 kg of fuel. The optimum airflow rate was $1.6m^3$/min and avg. percentage of white copra was found to be 55%. Dryer required 30 kg coconut husk to remove 1 kg of water from coconut halves. It indicates that dryer required relatively higher fuel to remove the moisture. Heating chamber of the dryer was also having large volume space ($0.50m^3$). Also, convection of heat from heating chamber to drying chamber through one single pipe limits the utilization of available heat energy in the heating chamber and there by reduces the efficiency of heat utilization tremendously. 40-45% heat loss observed during drying due to improper insulation of asbestos sheet. This dryer occupied more space and create difficulty in transportation. So there was target to make copra dryer as simple, compact, portable and give better result of drying.

Considering these results the dryer was tested for its drying performance by conducting 1.4 m^3/min and $1.6m^3$/min airflow rates. These tests were carried out on July 2008 and November 2008. 6-8kg fully matured coconuts of Banawali and T- Pratap variety was selected for test of drying. The coconuts were purchased from Horticultural department of Dr BSKKV Dapoli. 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 by the AOAC method (AOAC, 1975) for 130^0C for 1 hour. The chopped sample of 5 gm was selected for the determination of moisture content. Five replications were made for initial moisture content and average moisture content was taken.

The suitable airflow rate was fixed for blower and the dryer was run empty to attain the desired temperature i.e. 65° C. After attaining the temperature the halves were arranged on a tray in the drying chamber. The six halves were put at six different locations in the drying chamber. At every hour interval the weight loss of the each halves was measured and the loss of moisture content was determined. Fig. 3.2 shows the arrangement of cups in the drying chamber of CAET Dapoli developed copra dryer. The dryer was tested for various parameters, which are as follows:

3.2.1 Temperature measurement

In the drying chamber the temperatures were measured at different locations using digital thermometer. Also 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 Fig.3.3 shows schematic diagram showing locations of sensors to measure temperature in drying chamber of CAET Dapoli developed copra dryer. Fig.3.4 shows measurement of temperatures of drying chamber by digital thermometer at different locations of CAET Dapoli developed copra dryer. The temperatures were measured at two sensors i.e. T1 and T2, which located at the left and right side of drying chamber and the exhaust temperature also measured to study the temperature profile in the drying chamber because inside drying chamber from left side hot air come which was strike to the right side wall of drying chamber and then go to the atmosphere through exhaust pipe. The temperatures were measured by digital thermometer having range –50 to 150ºC.

3.2.2 Moisture removed

Amount of moisture to be removed from a given quantity of wet coconut was calculated using the formula given by Basunia M.A. *et.al*. (2001)

$$W_w = W_g \times \frac{M_i - M_f}{100 - M_f} \qquad (3.1)$$

Where,

W_w = Amount of moisture to be removed, kg

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

3.2.3 Drying rate,

The drying time, during which the drying takes place, is assumed to be 25 hrs. Average drying rate was determined from the mass of moisture to be removed and drying time by following expression.

$$R = \frac{W_w}{t_d} \qquad (3.2)$$

Where,

R = Drying rate

W_w = Amount of moisture removed, kg

t_d = Total drying time, hour.

3.2.4 Heat utilization factor

Heat utilization factor could be measure of drier performance. It may be defined as the ratio of temperature decrease due to cooling of the air during drying and the temperature increase due to heating of air. As H.U.F. decreases with decreasing drying efficiency. H.U.F. was calculated using the formula given by Chakraverty A. (1997).

$$\text{H.U.F.} = \frac{\text{Heat utilized}}{\text{Heat supplied}} = \frac{t_1 - t_2}{t_1 - t_0} \qquad (3.3)$$

Where,

t_1 = Dry bulb temperature of drying air, ºC

t_0 = Dry bulb temperature of ambient air, ºC

t_2 = Dry bulb temperature of exhaust air, ºC

3.2.5 The coefficient of performance

The coefficient of performance is a performance index of dryer. C.O.P. increases with decreasing drying efficiency. The coeffient of performance (C.O.P.) of dryer was calculated using the formula given by Chakraverty A. (1997).

$$\text{C.O.P.} = \frac{t_2 - t_0}{t_1 - t_0} \qquad (3.4)$$

OR

$$\text{H.U.F.} = 1 - \text{C.O.P.} \qquad (3.5)$$

3.2.6 Quality of copra

In the performance of the dryer with the machine efficiency the quality of the commodity were evaluated. The copra quality was measured with the parameters Colour, Protein and Fat. Colour parameter was measured by colourflex instrument. Protein estimation in the copra was determined by Kjeldahil method (AOAC,1970) by following expression,

$$\%\ \text{Protein} = \%\ \text{N} \times 6.25 \qquad (3.6)$$

Where,

$$\%\ \text{N} = \frac{(\text{V2} - \text{V3}) \times \text{Normality of HCl} \times 14}{\text{W}} \times 100$$

Where

V2 = ml of HCl used in determination

V3 = ml of HCl used in blank

W = weight of sample

Fat estimation was determined by Soxhlet apparatus method by AOAC (1970) by following expression,

$$\text{Fat content} = \% = \frac{\text{Weight of oil (g)}}{\text{Weight of sample (g)}} \times 100 \qquad (3.7)$$

3.3. Instruments used for measurement

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 to three locations in drying chamber were measured.

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%.

Air 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.The temperature for moisture measurement was maintained at 130 +- 1^{0}C and the sample were kept for 1 hour.

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.

Copra moisture meter

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

Color Flex measuring instrument

Color Flex instrument was used to measure color values by Hunter scale (Anonymous 1969,An ISO9001: 2000 certified company). Color values measured using color Flex are relative to the absolute value of a perfect reflecting diffuser as measured under the same geometric conditions (ASTM Method E308) according to January 1,1969 recommendation of the International Commission an Illumination, CIE. Thus in the Hunter scale, L measures lightness and varies from 100 for perfect white to zero for black, approximately as the eye would evaluate it. The chromaticity dimension (a and b) gives understandable designations of color as follows.

a measures redness when +ve, grey when zero and greenness when –ve

b measures yellowness when +ve, grey when zero and blueness when –ve

3.4 Modified CAET Dapoli copra dryer

The CAET Dapoli developed copra dryer can hold 6-8 kg coconut halves in single layer during drying, it indicates that drying capacity of dryer relatively less. This dryer required 30 kg fuel to remove 1 kg of water from coconut halves during drying period 30 hours from initial moisture content 50% to final moisture content 5.6% It indicates that dryer required relatively more fuel to remove moisture. 1200 – 1500 W heat loss observed during drying through heating chamber. Also convection of heat from heating chamber to drying chamber through one single pipe limits the utilization of available heat energy in the heating chamber and thereby reduces the efficiency of heat utilization tremendously. This dryer occupied more space ($3m^2$) and create difficulty in transportation. So in this point of view there was target to make copra dryer as simple, compact, portable and give better result of drying.

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

3.4.1. Design of a copra dryer

A dryer working on indirect heating and natural convection principles using coconut 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 with two trays
2. Heating chamber

3. Blower
4. Chimney

3.4.2. Assumptions for design of modified CAET Dapoli copra dryer

For the design of the dryer some assumptions were necessary. Density of coconut 450 kg/m^3 was assumed to calculate area of drying chamber. For calculation of airflow rate for drying were necessary to assumed initial moisture content 55% (w.b.), final moisture content 6% (w.b.), specific heat of water and coconut, latent heat of vaporization of water, drying period. Also to calculate fuel requirement for dryer were necessary to assumed calorific value of fuel, combustion efficiency, and heat exchanger efficiency. Table.3.1 shows assumptions for the design of the dryer were necessary.

Table 3.1 Assumptions for design of modified CAET Dapoli copra dryer

1. Initial moisture content of coconut (w.b.),	55%
2. Final moisture content of coconut (w.b.)	6%
3. Drying period of coconut, θ	25hr.
4. Drying temperature of air, t_2	75ºC
5. Temperature in drying	65ºC
6. Temperature of exhaust, t_1	40ºC
7. Initial temperature of coconut, t_{ci}	27ºC
8. Final temperature of coconut, t_{cf}	65ºC
9. Specific heat of water, C_{pw}	1 kcal/kgºC
10. Specific heat of coconut, C_{pc}	0.7 kcal/kgºC
11. Latent heat of vaporization of water	600 kcal/kg.
12. Calorific value of coconut waste, C_n	4500kcal/kg.
13. Weight of 100 coconuts halves, W	50kg
14. Thermal efficiency	25%
15. Heat exchanger efficiency, η_{ex}	35%
16. Combustion efficiency, η	65%
17. Density of coconut ρ_c	450 kg/m^3

3.4.3. Design parameters

On the basis of above assumptions the following considerations were put in the design of the dryer and drying system.

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,

$$A_d = \frac{\text{Mass of coconut}}{\text{Density of coconut} \times t_h} \tag{3.7}$$

Where,

A_d = Area of drying chamber, m^2

Mass of coconut = 50kg

Thickness of bed = 0.15m

Density of coconut = $450 kg/m^3$

$$Ad = \frac{50}{450 \times 0.15}$$

$= 0.7407$

$\approx 0.75 m^2$

The area of drying chamber = $0.75 m^2$

The thickness of bed for drying was considered by considering the geometric mean diameter thus the height of the cup was half of the geometric mean diameter. Thus considering the height of cup was 9 cm and considering the free space for air distribution the total bed thickness for drying was considered as 15cm. The two trays having dimensions 0.1m × 0.04m was design for drying chamber. The tray was made of perforated G.I. sheet having 0.02m diameter. The overall dimensions of the drying chamber were 1.25m (Length), 0.65m (Breadth) and 0.60m (height).The drying chamber was connected with heating chamber through angle just above the heating chamber.

Airflow rate

The rate of airflow required for drying can be calculated by making heat balance equation from the psychometric chart. Heat loss was assumed 30% (Chakraverty, 2000).

$$Q_a = G \times V_1 \tag{3.8}$$

Where,

Q_a = Airflow rate

V_1 = Humid volume in at air ambient air temperature (27^{o}C) and at 90% R.H. from psychometric chart.

= 0.86 m^3/ kg.

G = Rate of air supply in kg/min

$$G = \frac{W_1[(X_{id} - X_{fd})\lambda + C_{pc}(t_{ci} - t_{cf}) + C_{pw}(t_{ci} - t_{cf})X_{id}}{(0.24 + 0.45H)(t_2 - t_1)\theta \times 0.70} \tag{3.9}$$

Where,

W_1 = Bone dry coconut in kg. = 47kg

X_{id} = Initial moisture content of coconut, (d.b.) in fraction. = 1.22

X_{fd} = Final moisture content of coconut, (d.b.) in fraction. = 0.063

λ = Latent heat of water vapour in kcal/kg. = 600 kcal/kg

C_{pc} = Specific heat of coconut in kcal/kgºC. = 0.7 kcal/kg ^{o}C

C_{pw} = Specific heat of water in kcal/kgºC. = 1.0 kcal/kg ^{o}C

t_{ci} = Initial temp. of coconut in ºC. = 27 ^{o}C

t_{cf} = Final temp. of coconut in ºC. = 65 ^{o}C

H = Humidity at ambient air in kg/kg. = 0.02 kg/kg

t_2 = Drying temp. of air in ºC = 75 ^{o}C

t_1 = Temperature of exhaust air in ºC = 40 ^{o}C

θ = Drying period of coconut in hrs. = 30hrs

$$G = \frac{47[(1.22 - 0.063)600 + 0.7(62 - 27) + (65 - 27)1.2}{(0.24 + (0.45 \times 0.02))(75 - 40) \times 30 \times 60 \times 0.70}$$

= 3.27 kg/min

Q_a = 3.27× 0.86

$= 2.81 m^3/min$

$\approx 3\ m^3/min$

Air requirement for drying, $Q_a = 3\ m^3/min$

Fuel requirement

The rate of fuel consumption can be calculated as follows: (Chakraverty, 2000).

$$F = \frac{q_a}{\eta \times \eta_{ex} \times C_n} \qquad (3.10)$$

Where,

F = Fuel rate, kg/hr.

q_a = Total heat required to heat the drying air, kcal/hr.

$= W_1 [(X_{id} - X_{fd}) \lambda + C_{pc} (t_{ci} - t_{cf}) + C_{pw} (t_{ci} - t_{cf}) X_{id} \times \frac{1}{0.70} = 1715$ kcal/hr.

C_n = Calorific value of fuel, kcal/kg. = 4500 kcal/kg

η = Combustion efficiency. = 0.65

η_{ex} = Heat exchanger efficiency = 0.35

$$F = \frac{1715}{0.65 \times 0.35 \times 4500}$$

= 1.67kg/hr

Fuel rate = 1.67 kg/hr

From the quantity of fuel required the dimensions of the heating chamber were calculated. Considering free space the heating chamber was design. The overall dimensions of heating chamber were 1.00m (Length), 0.65m (Height) and 0.50m (width). The overall dimensions of furnace were 0.75m (Length), 0.35m (Height) and 0.35m (width). Opening of heating chamber was circular having diameter 0.23m. Heating chamber is placed just below the drying chamber.

Blower

The blower horsepower can be obtained by calculating the air requirement per unit area per unit time.

Horsepower of blower can be calculated as follows: (Kaleemullah, 2007)

$$Hp = \frac{P_d \times G}{4500} \qquad (3.11)$$

Where,

Hp = Blower horsepower

P_d = Pressure drop in the dryer, m of air.

G = Rate of air supply, kg/min.

The pressure drop in the drying chamber can be calculated by using the following formula (Chakraverty, 1988).

$$P_d = P_s \times L \times \frac{\rho_w}{\rho_a} \times \left(\frac{100}{100 - P_L} \right) \qquad (3.12)$$

Where,

Ps = Static pressure drop, m of water/ m length. = 9.9×10^{-4}m (Calculated from Shred's curve)

L = Length of drying chamber, m. = 1.25m

ρ_w = Density of water, kg/m^3. = 995.8kg/m^3

ρ_a = Density of air, kg/m^3. = 1.117kg/m^3

P_L = Pressure loss in conveying pipes etc, % = 50%

$$P_d = 9.9\times 10^{-4} \times 1.25 \times \frac{995.8}{1.177} \times \left(\frac{100}{100 - 50} \right)$$

= 2.0 m of air

Therefore

$$Hp = \frac{2.00 \times 3.27}{4500}$$

$= 1.45 \times 10^{-3}$

Hence smallest Hp blower available in the market is 0.25 Hp. Hence a blower motor of 0.25 Hp was used.

Blower = 0.25 Hp

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. (Basunia, 2001)

$$P = 0.000308 \times g \times (t_i - t_f) \times H \quad (3.13)$$

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) = $(2 \times P1 / \rho_e)^{0.5}$

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

For the design of chimney the pressure draft was calculated by considering the inside temp of gases in chimney and outside temperature 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.

H= 1m

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

P_1= 0.80 x 1.45

P_1 = 1.160 pa.

The velocity of exit air,

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

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

Volume of exit air,

$$V_e = \frac{0.05}{1.176}$$

$$V_e = 0.0425 m^3$$

Rate of exit air,

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

$$q_e = \frac{0.0425}{24}$$

$$q_e = 1.77\times 10^{-3} \text{ m}^3/\text{hr.}$$

Cross sectional area of chimney

$$\mathbf{a_c} = \frac{0.00177}{1.4}$$

$$a_c = 1.26\times 10^{-3} \text{ m}^2$$

Insulation

The thickness of insulation was determined by considering heat loss from the heating chamber and drying chamber. Therefore to avoid heat loss from the heating chamber and drying chamber the insulation was necessary. Considering the heat loss the thickness of the insulation was decided. Considering the thermal conductivity of the glass wool was used as an insulating material. The thermal conductivity of glass wool 0.044 W/m^{0}k. The temperature inside the heating chamber was found to be 450^{0}C and out side temperature was 150^{0}C. The heat loss was 1500W. The temperature inside the drying chamber was found to be 100^{0}C and out side temperature was 80^{0}C. The heat loss was 500W.

Therefore the thickness of insulation was,

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

Where

Q = Heat loss, Watt

K = Thermal conductivity of material, W/m^{o}K

T_i = Inside temperature of heating chamber or drying chamber, ^{o}K

T_o = Outside temperature of heating chamber or drying chamber, ^{o}K

x = Thickness of material, m

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

Therefore,

1) Thickness of insulation for drying chamber,

$$X = \frac{0.044 \times 0.75(100 - 80)}{500}$$

= 0.33cm

X = 3.3 × 10^{-3} m

2) Thickness of insulation for heating chamber,

$$X = \frac{0.044 \times 0.245(450 - 150)}{1500}$$

X = 0.2156cm

X = 2.2 × 10^{-3} m

The 0.33cm thick and 0.22cm thick glass wool material was used as insulation for drying chamber and heating chamber respectively.

3.5 Fabrication of modified CAET Dapoli copra dryer

3.5.1. Drying Chamber

The drying chamber was fabricated by using a mild steel sheet. The sheet used is of 22 gauge. Three sheets were required for the fabrication of the dryer. Angle frame of 3 mm, 1” x 1” was prepared and then three sheets were fitted in the frame and between two sheets insulating material glass wool was filled as per the dimensions. Two trays in drying chamber were made of two perforated G.I. sheet.

Angle frame of 3 mm, 1” x 1” was prepared and then one sheet was fitted in the frame. This tray was used for platform for copra during drying.

3.5.2. Heating chamber

For the heating chamber also M/s sheet of 16 gauge was used. The sheet was fitted in an angle frame of 5 mm, 1”x1”. Two sheets were required for the fabrication of the heating chamber and then two sheets were fitted in the frame and between two sheets insulating material glass wool was filled as per the dimensions.

3.5.3. Furance

For the fabrication of the furnace 700 mm x 350 mm mild steel square sheet of 18 gauge was used. Angle frame of 3 mm, 1” x 1” was prepared and then one sheet was fitted in the frame. Furnace i.e. burning cum heat exchanging unit was housed at the left side of heating chamber with circular opening having 0.23m diameter fitted below the drying chamber.

3.5.4. Chimney

Aluminum pipe having opening 3” x 2.5” was used for the fabrication of chimney. The chimney is fitted on the drying chamber as an outlet for the smoke to the atmosphere. This pipe was passed from below upper tray in drying chamber to the atmosphere. The purpose of taking this pipe through drying chamber was to utilized heat of flue gases for drying. No contact of smoke in drying chamber.

After the fabrication of the all parts the drying chamber was connected to the heating chamber through angle. The chimney was attached on the drying chamber as an outlet for the smoke. The furnace was fitted below the drying chamber housed at the left side of heating chamber.

The overall fabricated modified CAET Dapoli copra dryer is shown in Fig 3.5.

The material used for the fabrication of the dryer was listed below in the Table3.2. The fabrication was done in the workshop of College of Agricultural Engineering and Technology, Dapoli. The material used for the dryer was given below.

Table3.2. Material used for the fabrication of modified CAET Dapoli copra dryer

Material	Specifications	Quantity
M.S.angle	3mm 1”×1”	6nos.
M.S.angle	5mm 1”×1”	1nos.
M.S sheet	22 gauge 4’× 8’	3 nos.
M.S sheet	16 gauge 4’× 8’	2 nos.
Aluminum pipe	43”	3 nos.
Nut-Bolt	¼”×1”	250gm
Knifing paste filler	-	1kg
Wheel castor	50mm P.T. Fibron	4 nos.
Hinges	3”	4 nos.
Glass wool	-	6 kg
G.I. perforated sheet	16 gauge 4’× 8’	2nos.
M.S sheet	18 gauge 4’× 8’	1 nos.

The overall view of the dryer after fabrication and assembling is as shown in Fig. 3.7

3.6. Testing and evaluation of modified CAET Dapoli copra dryer.

The dryer was tested for its performance of drying. The dryer were tested using four airflow rates in the range of 0.0 m^3/min, 1.2 m^3/min, 1.4 m^3/min and 1.6 m^3/min in which 0.0m^3/min airflow rate means dryer tested without operating blower. These test conducted in January, February and March 2009. Drying chamber can hold 15-16 kg coconut halves in single layer. Each tray can hold 7-8 kg coconut halves. 15-16 kg fully matured coconuts of Banawali and T-Pratap variety was selected for drying test. The coconuts were purchase form Horticultural department of Dr. BSKKV’s Dapoli. 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 taken for the moisture content determination. Moisture content determination was done by the AOAC method (AOAC, 1975) for 130^{0}C for 1 hour. The chopped sample of 5 gm was taken for the determination of moisture content. Ten replications were made for initial moisture content and average moisture content was taken.

The suitable airflow rate was fixed for blower (0.25Hp) 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 both trays in the drying chamber. At every half hour interval the weight loss of both trays was measured and the loss of moisture content was determined. The Fig. 3.8 shows the arrangement of cups in the drying chamber.

Temperature measurement

In the drying chamber the temperatures were measured at different locations using digital thermometer. Also atmospheric relative humidity of ambient temperature was measured. The dryer was run for 8-9 hours in a day. The fuel was feed in a furnace for continuous burning. Temperature was controlled by adjusting the manual feeding rate of coconut husk to the furnace. The trial was continued till the moisture content of coconut was reduced to final moisture content of 6 % w.b.

The Fig.3.9 shows the schematic diagram showing locations of sensors to measure temperature in drying chamber of modified CAET Dapoli copra dryer. Fig. 3.10 shows Measurement of temperature of drying chamber by digital thermometer at different locations of modified CAET Dapoli copra dryer. The hourly observations of temperatures were measured at four sensors i.e. T_{UL} and T_{UR} means upper tray left side temperature and upper tray right side temperature respectively while T_{BL} and T_{BR} means bottom tray left side temperature and bottom tray right side temperature respectively. Exhaust temperature also measured to study the temperature profile in the drying chamber. The temperatures were measured by digital thermometer having range –50 to 150ºC.

Amount of moisture to be removed

Amount of moisture to be removed from a given quantity of wet coconut was calculated using the equation 3.1.

Drying rate

The drying time, during which the drying takes place, is assumed to be 25 hrs. Average drying rate was determined from the mass of moisture to be removed and drying time by equation 3.2.

Heat utilization factor

H.U.F. may be defined as the ratio of temperature decrease due to cooling of the air during drying and the temperature increase due to heating of air. H.U.F. was calculated using the equation 3.3.

Performance coefficient

The coeffient of performance (C.O.P.) of dryer was calculated using the equation 3.4. and equation 3.5.

Quality of copra

In the performance of the dryer with the machine efficiency the quality of the commodity were evaluated. The copra quality was measured with the parameters Colour, Protein and Fat. Colour parameter was measured by color Flex instrument. Protein estimation was done by Kjeldahil method by AOAC (1970) using equation 3.6 in section 3.2 while fat estimation in copra was done by Soxhlet apparatus method by AOAC (1970) using equation 3.7 in section 3.2.

RESULT AND DISCUSSIONS

The data obtained in the present investigation was analyzed. The results include data on testing of CAET Dapoli developed copra dryer, modification of CAET Dapoli developed copra dryer, testing and evaluation of modified CAET Dapoli copra dryer.

4.1 Testing of CAET Dapoli developed copra dryer

CAET Dapoli copra dryer have developed through M-Tech student (Sane, 2006) in the department of APE of Dr. BSKKV Dapoli. It is batch type indirect heating forced convection dryer. It consists of components was heating chamber, drying chamber, chimney, and air distritibution unit. Heating chamber is a separate unit which is having fuel tray. Chimney is provided to heating chamber for escape of smoke and air indirectly heated above the fuel box is conveyed to the drying chamber through 75 mm diameter of pipe with the help of blower having 0.70 Hp motor. Coconut husk (waste of coconut) was used as fuel for drying coconuts. The dryer can hold 6-8 kg coconut halves in single layer. The total spaced required for dryer unit is 3 m^2.

CAET Dapoli developed copra dryer was tested for its drying performance by conducting the test one each at the airflow rate 1.4m^3/min and second at 1.6 m^3/min airflow rate. It was tested for fuel consumption, drying capacity, drying temperature, heat generated heat utilized, heat loss, moisture removal and quality of material dried. For testing the dryer 8 kg coconut halves were used for 1.4 m^3/min airflow rate while 8.4 kg coconut halves used for 1.6m^3/min airflow rate. Initial moisture content was determined by AOAC (1975) method. 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 procedure of testing is described in section 3.2 of chapter third. The results are described for heating chamber, temperature in drying chamber and for drying of coconuts in following section.

4.1.1 Heating chamber

The overall dimensions of heating chamber of CAET Dapoli developed copra dryer were 0.65 m × 1 m × 1.2 m. Volume of heating chamber was 0.50 m^3. Coconut husk used as fuel to create fire in heating chamber. It occupied theoretically 8 kg fuel for 50per cent volume of heating chamber. The fuel burning rate observed during drying period was 4 kg/hr. 8-10 kg of coconut husk is required to have continuous fire in heating chamber. Heat from heating chamber is conveyed to drying chamber through one single pipe of 0.75 m diameter. Temperature in heating chamber observed was in the range of 450^{o}C - 500 ^{o}C and the temperature outside the wall of heating chamber observed was 200 ^{o}C which shows greater heat loss (1500 W) through the walls of heating chamber to the atmosphere due to lack of insulation. Also convection of heat from heating chamber to drying chamber through one single pipe limits the utilization of available heat energy in the heating chamber and thereby reduces the efficiency of heat utilization tremendously. The Fig.4.1 shows the heating chamber with fuel tray of CAET Dapoli copra dryer.

4.1.2 Temperature in drying Chamber

The overall dimensions of drying chamber of CAET Dapoli developed copra dryer were 1 m × 0.55 m × 0.60 m. It consist one tray in drying chamber. Volume of drying chamber was 0.42 m^3. The CAET Dapoli developed copra dryer were tested for two airflow rates in the range of 1.4 m^3/min and 1.6 m^3/min. For testing the dryer 8 kg coconut halves were used for 1.4 m^3/min airflow rate while 8.4 kg coconut halves used for 1.6 m^3/min airflow rate. Duration of drying observed was 30 hrs for 1.4 m^3/min and 1.6 m^3/min airflow rates.

The observations of temperature in drying chamber, exhaust air temperature, ambient air temperature and ambient relative humidity for drying were recorded during drying period are given in Appendix A1 and Appendix A2 respectively for 1.4 m^3/min and 1.6 m^3/min airflow rates. Table 4.1 and Table 4.2 are given the temperature data in drying chamber for 1.4 m^3/min and 1.6 m^3/min airflow rates respectively.

It was observed that the maximum temperature attained during 30 hours drying period was 71.2^oC for airflow rate 1.4m^3/min. Average relative humidity of ambient air observed was 56.85 per cent for airflow rate 1.4 m^3/min. It is also observed that the maximum temperature attained during drying was 69.5^oC through out 30 hours drying period for airflow rate 1.6 m^3/min and 55.37per cent average relative humidity of ambient air observed during drying for 1.6m^3/min airflow rate.

It was found that drying of coconut at 65 ^oC gives best quality of copra hence in drying chamber 65 ^oC was intended to obtain. The behaviour of temperature trend inside the drying chamber during the total drying period is shown in Fig.4.2 and Fig.4.3, respectively for 1.4m^3/min and 1.6m^3/min airflow rates. It is observed from Fig 4.2 and Fig.4.3, fluctuation of temperature inside the drying chamber was observed between 50 to 70 ^oC through out the four days of drying period and in both the airflow rates. The trend is of zigzag nature. It goes downwards and then upwards. Downward trend is due to diminishing (exhausting) power of fuel already burning and increasing trend is when heating chamber is re-fueled by putting coconut husk at every given time interval. Monitored regular feeding probably may help to minimize the temperature fluctuation inside the drying chamber. It is also observed that variation in drying temperature and exhaust air temperature due to heat utilized for drying. This behaviour of drying temperature and exhaust air temperature trend shown in Fig.4.4 and Fig.4.5.

4.1.3 Moisture removal

The CAET Dapoli developed copra dryer were tested for two airflow rates in the range of 1.4m^3/min and 1.6m^3/min. For testing the dryer 8 kg coconut halves were used for 1.4m^3/min airflow rate while 8.4 kg coconut halves used for 1.6m^3/min airflow rate. Duration of drying observed was 30 hrs for 1.4m^3/min and 1.6m^3/min airflow rates. The initial moisture content was determined by AOAC (1975) method. Initial moisture content was determining by air-oven method. Five replications were made and average moisture content was taken. Removal of moisture during the drying of copra was calculated from the weight loss of copra at

Table 4.1 Temperature observed in drying chamber during drying of coconut halves at airflow rate 1.4 m^3/min

Drying time	Temperature distritibution in drying chamber,^{O}C		
Hour	T1	T2	Avg. Td
First day			
1	68.6	65	66.8
2	62.2	58.2	60.2
3	55.2	51.4	53.3
4	65.8	63.4	64.6
5	71.2	67.2	69.2
6	61.4	62.3	61.85
7	53.8	55	54.4
8	58.8	60.8	59.8
		Avg.	**61.26**
Second day			
9	64.5	63.8	64.15
10	60.2	58.4	59.3
11	52.8	50.4	51.6
12	68.5	66.4	67.45
13	63.2	61.4	62.3
14	58.8	56.4	57.6
15	65.2	63.4	64.3
16	61.6	60	60.8
		Avg.	**60.93**
Third day			
17	66.6	64.8	65.7
18	62.4	61.8	62.1
19	56.6	54.6	55.6
20	52.8	50.4	51.6
21	65.5	63.8	64.65
22	63.6	61.8	62.7
23	60.4	58.8	59.6
24	69.2	67.6	68.4
		Avg.	**61.29**
Fourth day			
25	66.2	64.4	65.3
26	69.2	68	68.6
27	62.2	60.8	61.5
28	57.6	55.8	56.7
29	64.6	63.8	64.2
30	68.6	66.6	67.6
		Avg.	**63.98**

Table 4.2 Temperature observed in drying chamber during drying of coconut halves at airflow rate 1.6m^3/min

Drying time	Temperature distritibution in drying chamber, ^{O}C		
Hour	T1	T2	Avg. Td
First day			
1	61.2	60.5	60.85
2	58.8	56.2	57.5
3	62.8	60.6	61.7
4	69.6	68.2	68.9
5	63.4	60.6	62
6	52.2	50.8	51.5
7	68.5	65.8	67.15
8	58.2	56.2	57.2
		Avg.	**60.85**
Second day			
9	63.2	61.8	62.5
10	60	58.2	59.1
11	55.2	53.8	54.5
12	69.4	68.1	68.75
13	62.2	61	61.6
14	56.6	54.8	55.7
15	63.6	62	62.8
16	67.8	65.8	66.8
		Avg.	**61.4**
Third day			
17	65.8	63.6	64.7
18	60.2	59.2	59.7
19	52.2	50.6	51.4
20	68.6	66.2	67.4
21	61	59.8	60.4
22	55.2	53.8	54.5
23	64.8	63	63.9
24	60	58.2	59.1
		Avg.	**60.13**
Fourth day			
25	68.2	66.5	67.35
26	62.2	61.4	61.8
27	59.2	57.8	58.5
28	63.2	61.8	62.5
29	70.2	68.8	69.5
30	67.8	65.6	66.7
		Avg.	**64.39**

one-hour interval. Initial weight and moisture content were recorded for testing of each airflow rates. The data given in Appendix A3 and Appendix A4 for 1.4m^3/min and 1.6m^3/min airflow rates respectively. Moisture content and moisture removal was calculated using 1.4m^3/min and 1.6m^3/min airflow rates and data given in Table-4.3 and Table-4.4 respectively.

It was observed that for 1.4m^3/min airflow rate initial moisture content of coconut was 49.36per cent and it was dried to final moisture content of 5.46 per cent. It took 30 hours to remove 43.9 per cent of moisture from given 8 kg of coconut halves. Using 1.4 m^3/min airflow rate 3714 g of water was removed in 30 hours. Rate of removal of moisture from copra during each day interval reveals that rate was rapid during the initial drying of 8 hours (247.5 g/hr). It was 91.04 g/hr during second day drying interval, 72.42 g/hr in third day drying interval and 71.16g/hr in fourth day drying interval. On an average 124 g of water was removed per hour during the drying operation of 30 hours to dry coconut halves. Fuel consumed in the drying using 1.4 m^3/min airflow rate was 110 kg coconut husk. Using 1.4m^3/min airflow rate, fuel consumption rate to remove 1 kg water from coconut halves was 29.61 kg coconut husk. 8 kg coconut halves gave 3 kg of copra after drying. Fig.4.6 gives the moisture content profile with drying time (at 1.4m^3/min airflow rate). It is also observed that for 1.6m^3/min airflow rate initial moisture content of coconut was 50.00 per cent and it was dried to final moisture content of 5.57 per cent .It took 30 hours to remove total amount of 4093 g of water from given 8.4 kg of coconut halves. Rate of removal of moisture for each day was on an average 237.30 g/hr for first day, 174.32 g/hr during second day drying interval and 64.62 g/hr in third day drying interval and 47.21g/hr in fourth day drying interval. On an average 137 g of water was removed per hour during drying of 8.4 kg coconut halves in 30 hours. Fuel consumed in the drying for 1.6m^3/min airflow rate was 120 kg coconut husk. On an average 29.31 kg of coconut husk was utilized to remove 1 kg water from copra during drying from initial moisture content of 50 per cent to 5.57 per cent final moisture content. 8.4 kg coconut halves gave 3.2 kg of copra after drying. Fig.4.7 explains the moisture content profile with drying time 1.6 m^3/min airflow rates.

Table 4.3 Drying data during copra drying at air flow rate of 1.4m^3/min

Drying time	Moisture content (w.b.)	Moisture removed	Drying rate,R
hours	**%**	**g**	**kg/hr**
First day			
0	49.36	0	0
1	47.33	308.00	0.31
2	45.31	592.43	0.30
3	42.84	912.93	0.30
4	40.11	1230.00	0.31
5	38.73	1390.00	0.28
6	36.23	1650.00	0.27
7	34.24	1840.00	0.26
8	32.64	1980.00	0.25
	Avg.	**247.5**	
Second day			
9	31.28	2103.54	0.23
10	30.02	2209.62	0.22
11	29.02	2290.71	0.21
12	28.06	2367.24	0.20
13	27.32	2424.91	0.19
14	25.99	2524.54	0.18
15	24.81	2610.62	0.17
16	23.41	2708.36	0.17
	Avg.	**91.04**	
Third day			
17	22.26	2786.12	0.16
18	20.48	2902.20	0.16
19	19.05	2992.40	0.16
20	17.81	3067.89	0.15
21	16.88	3123.49	0.15
22	15.55	3198.37	0.15
23	14.70	3246.95	0.14
24	13.95	3287.74	0.14
	Avg.	**72.42**	
Fourth day			
25	13.42	3318.40	0.13
26	11.18	3436.99	0.13
27	9.47	3523.16	0.13
28	7.77	3606.07	0.13
29	6.30	3675.36	0.13
30	5.46	3715	0.12
	Avg.	**71.16**	

Table 4.4 Drying data during copra drying at air flow rate of 1.6m^3/min

Drying time	Moisture content (w.b.)	Moisture removed	Drying rate,R
Hours	**%**	**g**	**kg/hr**
First day			
0	50.00	0.00	0
1	47.91	349.30	0.35
2	46.03	638.66	0.32
3	44.24	898.10	0.30
4	42.42	1143.70	0.29
5	40.80	1351.01	0.27
6	39.35	1525.31	0.25
7	37.64	1720.92	0.25
8	36.01	1898.44	0.24
	Avg.	**237.50**	
Second day			
9	34.20	2085.66	0.23
10	32.01	2297.12	0.23
11	29.94	2485.50	0.23
12	27.69	2678.70	0.22
13	25.49	2854.47	0.22
14	23.49	3006.61	0.21
15	21.52	3150.06	0.21
16	19.44	3293.03	0.21
	Avg.	**174.32**	
Third day			
17	17.52	3417.83	0.20
18	15.93	3519.14	0.20
19	14.92	3579.97	0.19
20	14.23	3622.24	0.18
21	13.44	3669.34	0.17
22	12.56	3720.68	0.17
23	11.60	3775.14	0.16
24	10.97	3810.01	0.16
	Avg.	**64.32**	
Fourth day			
25	10.55	3834.67	0.15
26	9.63	3884.42	0.15
27	8.83	3926.72	0.15
28	7.86	3977.87	0.14
29	6.56	4043.88	0.14
30	5.57	4093.31	0.14
	Avg.	**47.21**	

4.1.4. Quality of copra

Quality of copra dried for airflow rates 1.4 m^3/min and 1.6 m^3/min were evaluated by three parameters color, protein fat and copra. Colour of copra were decided from L, a, b values measured by colorflex instrument and which are given in Appendix A5 Appendix A6. Copra was graded in two grades i.e. white copra and brown copra. Influence of airflow rate on colour of copra is shown in Table 4.5.

Table 4.5 Colour analysis of copra

Airflow rate	Colour of copra	
m^3/min	**%**	**%**
	White copra	Brown copra
1.4	52.5	47.5
1.6	56.81	43.18

It was observed that per cent of white copra was more in case of 1.6 m^3/min airflow rate as compared to 1.4 m^3/min airflow rate.

Protein estimation was done by Kjeldahil method by AOAC (1970). The data on protein value is given in Appendix A7. Protein value of copra is shown in Table 4.6.

Table 4.6 Protein analysis of copra

Airflow rate	Protein	
m^3/min	%	%
	White copra	Brown copra
1.4	5.25	5.27
1.6	5.73	5.75

Average protein found was 5.26 per cent for 1.4 m^3/min airflow rate while 5.74 per cent for 1.6m^3/min airflow rate.

Fat estimation was done by Soxhlet apparatus method by AOAC (1970). The data on fat percentage is given in Appendix A8. Fat value of copra is shown in Table 4.7

Table 4.7 Fat analysis of copra

Airflow rate	Fat	
m^3/min	%	%
	White copra	Brown copra
1.4	56.67	54.67
1.6	57.33	56

Average fat found was 55.67 per cent for 1.4m^3/min airflow rate while average fat found was 56.66 per cent for 1.6m^3/min airflow rate.

The considering parameters Colour, protein and fat of copra, the colour of the copra should white for good copra quality with 6 per cent final moisture content of copra. Good quality of copra gives 60-62 per cent fat while 6-7 percent protein. The CAET Dapoli developed copra dryer gave on an average 55 per cent white copra, 56 per cent fat and 5 per cent protein.

4.1.5 Performance of CAET Dapoli developed copra dryer

CAET Dapoli developed copra dryer was tested for fuel consumption, drying capacity, drying temperature, heat generated heat utilized, heat loss, moisture removal and quality of dried material. The dryer was tested for two airflow rates i.e. 1.4 m^3/min and 1.6 m^3/min. Observations of H.U.F. and C.O.P. were recorded and given in Appendix A9 and Appendix A10 for airflow rates 1.4 m^3/min and 1.6 m^3/min, respectively.

It is found that in batch drying of copra H.U.F. was found less than unity. The amount of heat utilized goes on decreasing with increase in exhaust air temperature and time. As H.U.F. increases drying efficiency increases. Testing of CAET Dapoli developed copra dryer were found that the during drying test first using 1.4m^3/min airflow rate has consumed 110 kg of coconut husk for drying coconut halves from initial moisture content 49.36 per cent to final moisture content 5.46 per cent and drying test second using 1.6 m^3/min airflow rate has consumed 120 kg of coconut husk for drying coconut halves from initial moisture content 50.00 per cent to final moisture content 5.57 per cent. On an average 120 kg fuel required to dry 8 kg coconut halves. On an average 124 g of water is removed per hour for 1.4 m^3/min airflow rate while 137 g of water removed per hour for 1.6 m^3/min. On an average 30 kg coconut husk required to remove only 1 kg of water from coconut halves from initial moisture content 50 per cent to final moisture content 6 per cent. It indicates that dryer required relatively more fuel to remove the moisture. Fuel chamber of the dryer is also having large volume space (0.28 m^3). Also convection of heat from heating chamber to drying chamber through one single pipe limits the utilization of available heat energy in the heating chamber and thereby reduces the efficiency of heat utilization tremendously. It is observed that 40-45 per cent heat loss through heating chamber wall due to lack of insulation. Total spaced required for dryer unit is 3 m^2 which create difficulty in transportation.

4.2 Design of modified CAET Dapoli copra dryer

CAET Dapoli developed copra dryer was tested for two airflow rates in the range of 1.4 m^3/min and 1.6 m^3/min for fuel consumption, drying capacity, drying temperature, heat generated heat utilized, heat loss, moisture removal and quality of material dried. The results obtained are broadly summarised as below:

- Average 120 kg fuel consumed to dry 8 kg coconut halves. On an average 30 kg coconut husk required to remove only 1 kg of water from coconut halves from initial moisture content 50 per cent to final moisture content 6 per cent. It indicates that dryer required relatively more fuel to remove the moisture.
- Fuel chamber of the dryer is also having large volume space (0.28 m^3). Also convection of heat from heating chamber to drying chamber through one single pipe limits the utilization of available heat energy in the heating chamber and thereby reduces the efficiency of heat utilization tremendously. It is observed that 40-45 per cent heat loss (1500 W) through heating chamber wall due to lack of insulation.
- Average 4000 g water removed from drying of 8 kg coconut halves through out total 30 hours drying period from initial moisture content 50 per cent to final moisture content 6 per cent.
- Total space required for dryer unit is 3m^2, which creates more difficulty in transportation.
- On average white copra found was 55 per cent after drying of coconut halves.

These results shows that CAET Dapoli copra dryer required to modify for increasing drying capacity, less fuel requirement, moisture removed per hour more using less fuel, avoid heat loss from heating chamber wall, dryer make compact, portable easy for transportation and improve quality of copra. This point of view CAET Dapoli developed copra dryer were modified by new design. The design parameters, equation, their calculations, fabrications and testing procedure described in 3.4, 3.5 and 3.6 section in chapter third.

The results of modification of CAET Dapoli copra dryer are discussed as follows:

In the modified copra dryer, the area of drying chamber kept was $0.75 m^2$.Drying chamber consisted two trays having dimensions 0.1m×0.04m.The overall dimension of drying chamber was 1.25 m× 0.65 m×0.60 m. (Fig.4.8). The maximum airflow was selected as $3 m^3$/min; pressure drop in the dryer found was 2.0m of air. Horse power of blower for dryer determined was 1.45×10^{-3} Hp. Hence smallest Hp blower available in the market is 0.25 Hp, so 0.25 Hp blower was selected and fitted to the dryer. Using total heat required and calorific value of coconut husk fuel rate decided by using equation 3.10 was 1.67 kg/hr. Using the quantity of coconut husk required, the dimensions of heating chamber were calculated. The overall dimensions of furnace i.e. burning cum heat exchanger were 0.75 m × 0.35 m × 0.35 m. The overall dimensions of heating chamber were 1 m × 0.65 m × 0.50 m. Opening of furnace was circular having diameter 0.23 m. The height of chimney decided by using equation 3.13 was 1m while area of chimney was $1.26 \times 10^{-3}\ m^2$. To avoid heat loss insulation was provided to dryer. Glass wool was used as insulating material. The thickness of insulation was determined by considering the heat loss from the heating and drying chamber using equation 3.14. The 0.33 cm thick and 0.22 cm thick glass wool material was used as insulation for drying and heating chamber.

The overall specifications of modified CAET Dapoli copra dryer and CAET Dapoli developed copra dryer is tabulated in Table 4.8

4.3 Testing and evaluation of Modified CAET Dapoli copra dryer

Modified CAET Dapoli copra dryer have developed by considering the results of drying of CAET Dapoli copra dryer. It is batch type indirect natural convection dryer. It consists of four components i.e. heating chamber, drying chamber with two trays, chimney and blower. Drying chamber, heating chamber, exhaust pipe and chimney are not separate unit which are built in one section as one unit. Aluminum pipe was used as chimney to escape smoke to atmosphere. This Aluminum pipe was passed out to atmosphere through below upper tray in drying chamber. The purpose of taking this pipe through drying chamber was to utilize heat of flue gases for drying as energy saving. No contact of smoke in drying chamber. Coconut husk used as fuel to create fire in heating chamber. Heat from heating chamber is conveyed to drying chamber by convection current. This heat transfer generates a convection air current. The hot air moves up through the wet produce kept in drying chamber. 0.25 Hp blower attached below the drying chamber just another side of heating chamber for uniform circulation of hot air in drying chamber. The total space required for dryer unit is $0.81 m^2$. The dryer can hold 15-16 kg coconut halves in single layer.

Table: 4.8 Dimensional changes in modified CAET Dapoli copra dryer after comparison with CAET Dapoli developed copra dryer

Sr. No.	Parameter	CAET Dapoli developed copra dryer	Modified CAET Dapoli copra dryer
1	Overall dimensions of drying chamber (L×B×H)	1 m ×0.55 m × 0.66 m	1.25 m ×0.65 m × 0.60 m
2	Overall dimensions of heating chamber (L×B×H)	1.65×1 m×1.2 m	1m×0.65 m×0.50 m
3	Overall dimensions of furnace (L×B×H)	0.60 m×080 m×0.60 m	0.75 m ×0.35 m × 0.35 m
4	Area of drying chamber (m^2)	0.44	0.75
5	Area of heating chamber (m^2)	0.65	0.24
6	Volume of drying chamber,m^3	0.42	0.49
7	Volume of heating chamber, m^3	0.50	0.32
8	Volume of furnace, m^3	0.28	0.08
9	No of trays in drying chamber	1	2
10	Space required for dryer unit,m^2	3	0.81
11	Height of the dryer (m)	2.2	1.88
12	Blower (hp)	0.7	0.25
13	Coconut halves holding capacity in drying chamber for single layer, kg	6-8 kg	15-16 kg
14	Fuel holding capacity, kg (50per cent of volume of heating chamber)	8	3

Modified CAET Dapoli copra dryer was tested for fuel consumption, drying capacity, drying temperature, heat generated, heat utilized, heat loss, moisture removal and quality of material dried. The dryer was tested for three airflow rates i.e 1.2 m^3/min 1.4 m^3/min and 1.6 m^3/min. Drying done without blower is taken as control (0.0 m^3/min airflow rate). The dryer were 15.85 kg and 12.85 kg coconut halves used for drying test for control (0.0 m^3/min), 1.2 m^3/min airflow rates, respectively while 15.19 kg and 11.88 kg coconut halves used for 1.4m^3/min and 1.6 m^3/min airflow rates respectively. Initial moisture content was determined by AOAC method (1975). Ten replications were made for initial moisture content and average moisture content was taken. The dryer was run empty to attain the desired temperature (65º C). After attaining the temperature the halves were arranged on an upper tray and bottom tray in the drying chamber. The procedure of testing is described in Section 3.6, chapter III. The results are described for heating chamber, temperature in drying chamber and drying of coconuts in following Sections.

4.3.1 Heating chamber

The overall dimensions of heating chamber of modified CAET Dapoli copra dryer are 1m×0.65m×0.50m. The overall dimensions of furnace i.e. burning cum heat exchanger are 0.75 m × 0.35 m × 0.35 m. Volume of heating chamber is 0.32 m^3. Volume of furnace is 0.08m^3. Coconut husk used as fuel to create fire in heating chamber. Fuel holding capacity is considered as theoretically 50 per cent of volume of furnace i.e.3 kg. The fuel-burning rate observed during drying period was 1 kg/hr. Three to Four kg of coconut husk is required to have continuous fire in heating chamber. Heat from heating chamber is conveyed to drying chamber by convection current. Temperature in heating chamber observed was in the range of 450^{o}C - 500^{o}C and the temperature outside the wall of heating chamber observed was 50^{o}C which showed less heat loss (150 W) through the walls of heating chamber to the atmosphere as compared to CAET Dapoli developed copra dryer because glass wool insulation provided to walls of heating chamber in modified CAET Dapoli copra dryer. It is found that 15-20 per cent heat utilized for copra drying because copra drying have limits of temperature range i.e. it required 60-65^{o}C temperature in drying chamber. Temperature of drying chamber was controlled by adjusting the manual feeding rate of coconut husk to heating chamber. Fig. 4.9 shows heating chamber with furnace of modified CAET Dapoli copra dryer.

4.3.2 Temperature in drying chamber

The overall dimensions of drying chamber of modified CAET Dapoli copra dryer were 1.25 m × 0.65 m × 0.60 m. It consists two trays in drying chamber. Volume of drying chamber was 0.49m^3. The dryer was tested for three airflow rates in the range of 1.2 m^3/min 1.4 m^3/min and 1.6 m^3/min. Drying done for control (0.0 m^3/min airflow rate) means dryer tested for without operating blower. The dryer were hold 15.85 kg and 12.85 kg coconut halves for 0.0 m^3/min, 1.2m^3/min airflow rates respectively while 15.19 kg and 11.88 kg coconut halves hold for 1.4 m^3/min and 1.6m^3/min airflow rates respectively. Dryer took 32 hours and 29 hours drying period for 0.0 m^3/min, 1.2 m^3/min airflow rates respectively while 30 hours and 21 hours drying period required for 1.4 m^3/min and 1.6 m^3/min airflow rates, respectively.

Temperature plays important role in copra drying, 0.25 Hp blower was selected to provide airflow rates in the range of 1.2 m^3/min, 1.4 m^3/min and 1.6 m^3/min. Observations of upper tray temperature and bottom tray temperature in drying chamber, exhaust air temperature were recorded by using blower and also without blower (0.0 m^3/min airflow rate). The temperature data for whole drying is shown in Appendix A11 and Appendix A12 using 0.0 m^3/min, 1.2m^3/min airflow rates, respectively. The temperature data for 1.4 m^3/min, 1.6 m^3/min airflow rates is given in Appendix A13 and Appendix A14, respectively. Table 4.9 Table 4.10 presents the temperature data observed in drying chamber using airflow rates 0.0 m^3/min, 1.2m^3/min, respectively. The data for temperature observed in drying chamber for airflow rates1.4 m^3/min and 1.6m^3/min is tabulated in Table 4.11 and Table 4.12, respectively.

It is observed that the temperature in drying chamber was varied between 67^{o}C to 69^{o}C for drying without using blower (0.0 m^3/min airflow). Temperature at the bottom tray was relatively higher than that at the upper tray by 2

^{o}C to 3 ^{o}C. This is probably due to the closeness of bottom tray to the (furnace) heating chamber. Fig 4.10 shows temperature inside drying chamber for 0.0 m^3/min airflow rate.

Temperatures in the drying chamber were in the range of 65 ^{o}C to 67 ^{o}C when blower was operates for airflow rate of 1.2 m^3/min. Fig.4.11 present the temperature profile inside drying chamber. It was 63.6 ^{o}C to 66.29 ^{o}C when airflow rate was 1.4 m^3/min and 63.8^{o}C to 65.8^{o}C for airflow rate of 1.6 m^3/min. Fig.4.12 and Fig.4.13 gives temperature in drying chamber for 1.4m^3/min and 1.6m^3/min airflow rates respectively.

It is observed that increase in airflow rate decrease drying temperature by 2 ^{o}C to 3 ^{o}C. It is also observed that variation in drying temperature and exhaust air temperature due to heat utilized for drying. The behaviour of drying temperature and exhaust air temperature trend shown in Fig.4.14 and Fig.4.15 for airflow rates 0.0 m3/min, 1.2 m^3/min. The behaviour of drying temperature and exhaust air temperature trend plotted in Fig.4.16 and Fig.4.17 for airflow rates 1.4 m3/min, 1.6 m^3/min.

4.3.3 Moisture removal

The modified CAET Dapoli copra dryer were tested for four airflow rates in the range of 0.0 m^3/min, 1.2m^3/min 1.4m^3/min and 1.6m^3/min in which for 0.0 m^3/min airflow rate means dryer tested for without operating blower. The dryer were used 15.85 kg and 12.85 kg coconut halves during drying test using 0.0 m^3/min, 1.2m^3/min airflow rates respectively while 15.19 kg and 11.88 kg coconut halves used for 1.4m^3/min and 1.6m^3/min airflow rates respectively. Dryer took 32hours and 29 hours drying period for 0.0 m^3/min, 1.2m^3/min airflow rates respectively while 30 hours and 21 hours drying period required for 1.4m^3/min and 1.6m^3/min airflow rates respectively. The initial moisture content was determined by AOAC method (1975). Ten replications were made for initial moisture content and average moisture content was taken. Removal of moisture during the drying of copra was calculated from the weight loss of upper tray and bottom tray at one hour interval. Initial weight and moisture content were recorded for testing of each airflow rates. The data described

Table: 4.9 Temperature profile in drying chamber for airflow rate 0.0m3/min

Drying time	Temperature distribution in drying chamber ^{o}C	
hour	Avg.T_U	Avg.T_B
First day		
1	58.85	59.60
2	71.20	73.95
3	74.50	78.75
4	70.90	74.50
5	67.05	69.00
6	71.75	75.55
7	73.00	77.45
8	64.95	66.10
Average	**69.03**	**71.86**
Second day		
9	61.60	64.85
10	66.80	69.45
11	71.55	78.75
12	65.80	68.25
13	69.40	72.15
14	69.45	72.25
15	61.80	60.50
16	70.85	74.15
17	70.65	73.85
Average	**67.54**	**70.47**
Third day		
18	68.80	70.70
19	72.10	73.55
20	60.00	59.75
21	66.20	67.65
22	60.65	60.50
23	64.45	65.50
24	66.00	67.20
25	68.45	69.85
26	68.20	69.10
Average	**66.09**	**67.09**
Fourth day		
27	64.90	66.35
28	68.45	69.80
29	65.40	67.75
30	62.65	64.30
31	65.60	68.50
32	70.10	71.30
Average	**66.42**	**68.02**
Total Average	**67.27**	**69.36**

Table: 4.10 Temperature profile in drying chamber for airflow rate 1.2m3/min

Drying time	Temperature distribution in drying chamber °C	
hour	Avg.T_U	Avg.T_B
First day		
1	70.05	61.50
2	65.35	61.00
3	70.15	62.95
4	62.75	63.10
5	69.40	69.20
6	67.80	62.65
7	69.40	65.30
8	68.90	63.80
Average	**67.98**	**63.69**
Second day		
9	62.55	68.90
10	68.80	67.05
11	68.05	68.35
12	63.25	59.35
13	69.35	66.30
14	67.95	71.15
15	69.35	64.60
16	71.10	66.20
17	68.15	63.80
Average	**67.62**	**66.19**
Third day		
18	66.80	64.50
19	71.80	72.95
20	65.65	66.30
21	62.75	59.45
22	71.60	69.35
23	67.65	62.25
24	65.15	64.30
25	69.00	63.60
Average	**67.55**	**65.34**
Fourth day		
26	67.45	69.25
27	63.90	63.90
28	68.15	63.70
29	66.40	62.85
Average	**66.48**	**63.48**
Total Average	**67.40**	**64.67**

Table: 4.11 Temperature profile in drying chamber for airflow rate 1.4m^3/min

Drying time	Temperature distribution in drying chamber ^oC	
hour	Avg.T_U	Avg.T_B
First day		
1	69	57.65
2	61.3	59.35
3	64.3	60.05
4	62.3	65.80
5	65.7	70.95
6	68.1	63.30
7	71.55	69.50
8	69.35	62.50
Average	**66.45**	**63.64**
Second day		
9	64	63.70
10	67.9	59.40
11	64.3	58.30
12	63	58.95
13	67.3	67.40
14	72.9	72.05
15	69.15	62.80
16	69.5	63.70
17	65.6	61.85
Average	**67.07**	**63.13**
Third day		
18	68.05	61.00
19	71	64.90
20	58.2	60.00
21	69.95	71.65
22	65.25	67.70
23	62.15	61.10
24	65.05	63.50
25	67.7	65.30
Average	**65.92**	**64.39**
Fourth day		
26	66	66.80
27	63.8	61.00
28	70.4	64.50
29	62.15	56.20
30	63.6	67.00
Average	**65.19**	**63.1**
Total Average	**66.16**	**63.56**

Table: 4.12 Temperature profile in drying chamber for airflow rate1.6m3/min

Drying time	Temperature distribution in drying chamber ^{o}C	
hour	Avg.T_U	Avg.T_B
First day		
1	63.95	59.95
2	70.6	67.30
3	68.9	65.35
4	63.85	67.90
5	63.05	63.75
6	64.1	63.15
7	62.1	61.35
8	69.4	65.25
Average	**65.74**	**64.25**
Second day		
9	63.15	63.55
10	66	65.35
11	62.95	58.25
12	69.25	60.35
13	69.95	71.70
14	58.9	60.65
15	70.65	62.55
16	68.25	67.25
17	69.4	69.45
Average	**66.50**	**64.34**
Third day		
18	64.25	55.00
19	64.05	62.40
20	69.85	64.00
21	62.3	65.80
Total Average	**65.11**	**61.80**

in Appendix A15 and Appendix A16 for 0.0m^3/min and 1.2m^3/min airflow rates while Appendix A17 and Appendix A18 for 1.4m^3/min and 1.6m^3/min airflow rates, respectively. Moisture content and moisture removal was calculated and given in Table-4.13 and Table-4.14 for 0.0m^3/min, 1.2m^3/min airflow rate respectively. Table-4.15 and Table-4.16 given data on moisture content and moisture removal behaviour for 0.0 m^3/min, 1.2 m^3/min airflow rate respectively.

15.85 kg coconut halves took for drying at 0.0 m^3/min airflow rate. Initial moisture content of coconut halves was 52.71per cent (w.b.) and it was dried to 4.81per cent (w.b.). It took 32 hours to remove 5633 g of water from given 15.85 kg drying of coconut halves. Rate of removal of moisture from copra during each day interval reveals that rate was rapid during the initial drying of 8 hours (305 g/hr). It was 267 g/hr during second day drying interval, 52 g/hr in third day drying interval and 53 g/hr in fourth day drying interval. On an average 176.03 g of water is removed per hour. Fuel consumed for drying coconut halves using 0.0 m^3/min airflow rate was 18 kg coconut husk. 3.19 kg coconut husk is utilized to remove 1 kg of water from coconut halves during drying from initial moisture content 52.71 per cent to 4.81 per cent final moisture content. 5.8 kg of copra got from drying of 15.85 kg coconut halves in 32 hours drying period. Fig. 4.18 shows moisture content behaviour during 32 hour drying period for 0.0 m^3/min airflow rate.

12.85 kg coconut halves took for drying at 1.2 m^3/min airflow rate, from initial moisture content of coconut halves was 49.99 per cent (w.b.) to 5.11 per cent (w.b.). It took 29 hours to remove 5272 g of water from given 12.85 kg drying of coconut halves. Rate of removal of moisture from copra during each day interval was on an average 294 g/hr for first day 159 g/hr for second drying interval, 134 g/hr for third day drying interval and 93 g/hr for fourth day drying interval. On an average 182 g of water is removed per hour. Fuel consumed for drying coconut halves for 0.0 m^3/min airflow rate was 20 kg coconut husk for drying of 12.85 kg coconut halves. 3.79 kg coconut husk is utilized to remove 1 kg of water from coconut halves during drying from initial moisture content 49.99 per cent to 5.11 per cent final moisture content. 4.29 kg of copra got from drying of 12.85 kg coconut halves in 29 hours drying period. Fig. 4.19 shows moisture content behavior during 29 hour drying period for 1.2 m^3/min airflow rate.

Table 4.13 Moisture content and moisture removal behaviour for 0.0m^3/min airflow rate

Drying time	Moisture content (w.b.)	Moisture removed
hour	%	g
First day		
0	52.71	0
1	50.47	511
2	48.81	862
3	46.78	1262
4	45.23	1540
5	43.60	1826
6	42.22	1849
7	40.92	2253
8	39.68	2440
	Mean	**305.6**
Second day		
9	35.76	2967
10	35.18	3038
11	33.96	3193
12	23.57	4289
13	21.57	4467
14	20.49	4566
15	18.77	4701
16	17.81	4782
17	16.93	4850
	Mean	**267.77**
Third day		
18	14.25	5050
19	13.71	5087
20	13.11	5134
21	12.73	5107
22	11.99	5218
23	11.80	5225
24	11.19	5272
25	10.90	5288
26	10.51	5311
	Mean	**51.22**
Fourth day		
27	8.86	5414
28	8.33	5457
29	7.85	5489
30	7.19	5525
31	6.54	5571
32	5.60	5633
	Mean	**52.33**

Table 4.14 Moisture content and moisture removal behaviour for 1.2m^3/min airflow rate

Drying time	Moisture content (w.b.)	Moisture removed
hour	%	g
First day		
0	49.99	0
1	47.87	463
2	46.02	828
3	43.90	1228
4	42.66	1440
5	41.23	1683
6	39.45	1963
7	37.65	2219
8	36.77	2357
	Mean	**294.63**
Second day		
9	34.28	2685
10	33.04	2853
11	32.14	2957
12	30.88	3109
13	29.83	3229
14	29.11	3318
15	28.13	3426
16	27.18	3523
17	24.70	3786
	Mean	**159**
Third day		
18	19.21	4292
19	17.24	4457
20	15.42	4602
21	13.66	4736
22	12.46	4823
23	11.62	4879
24	10.86	4936
25	10.35	4973
26	10.10	4994
	Mean	**134**
Fourth day		
27	8.88	5078
28	7.05	5204
29	6.06	5272
	Mean	**92.66**

Table 4.15 Moisture content and moisture removal behaviour for 1.4m^3/min airflow rate

Drying time	Moisture content (w.b.)	Moisture removed
hour	%	g
First day		
0	56.46	0
1	54.42	676
2	52.65	1223
3	51.01	1681
4	50.03	1945
5	48.64	2306
6	47.07	2692
7	45.29	3096
8	43.50	3481
	Mean	**435.13**
Second day		
9	39.92	4184
10	38.50	4437
11	37.17	4659
12	36.44	4784
13	35.90	4868
14	34.95	5023
15	33.54	5236
16	30.60	5653
17	28.66	5910
	Mean	**347.65**
Third day		
18	25.16	6347
19	24.41	6432
20	23.91	6490
21	21.16	6795
22	19.67	6954
23	17.62	7158
24	16.96	7224
25	15.64	7310
	Mean	**292.40**
Fourth day		
26	13.88	7507
27	11.93	7673
28	9.89	7846
29	8.18	7990
30	6.52	8114
	Mean	**270.47**

Table 4.16 Moisture content and moisture removal behaviour for 1.6m^3/min airflow rate

Drying time	Moisture content (w.b.)	Moisture removed
hour	%	g
First day		
0	42.52	0
1	38.95	699
2	36.87	1074
3	35.45	1306
4	33.85	1563
5	32.07	1839
6	30.30	2094
7	28.33	2360
8	27.40	2477
	Mean	**309.43**
Second day		
9	24.89	2796
10	22.63	3058
11	20.28	3325
12	13.12	4025
13	11.97	4125
14	10.97	4214
15	10.04	4290
16	8.65	4406
17	7.55	4497
	Mean	**244.44**
Third day		
18	5.64	4650
19	5.25	4681
20	4.86	4711
21	4.59	4731
	Mean	**58.50**

It was observed for 1.4m^3/min airflow rate, 15.19 kg coconut halves took for drying. Initial moisture content of coconut halves was 56.46 per cent (w.b.) and it was dried to 6.62 per cent (w.b.). It took 30 hours to remove 8114 g of water from 15.19 kg drying of coconut halves. Rate of removal of moisture from copra during each day interval observed that rate was rapid during the initial drying of 8 hours (435 g/hr). It was 270 g/hr during second day drying interval, 175 g/hr in third day drying interval and 161 g/hr in fourth day drying interval. On an average 271 g of water is removed per hour. Fuel consumed for drying coconut halves for 1.4 m^3/min airflow rate was 25 kg coconut husk.3.08 kg coconut husk is utilized to remove 1 kg of water from coconut halves during drying from initial moisture content 56.46 per cent to 6.62 per cent final moisture content. 6.23 kg of copra got from drying of 15.19 kg coconut halves in 30 hours drying period. Fig. 4.20 shows moisture content behavior during 30 hour drying period for 1.4m^3/min airflow rate.

It was observed that for 1.6 m^3/min airflow rate, 11.88 kg coconut halves took for drying. Initial moisture content of coconut halves was 42.52 per cent (w.b.) and it was dried to 5.58 per cent (w.b.). It took 21 hours to remove 4731g of water from given drying lot of coconut halves. Rate of removal of moisture from copra during each day interval reveals that rate was rapid during the initial drying of 8 hours (309 g/hr). It was 244 g/hr during second drying interval, 59 g/hr in third drying interval. On an average 226 g of water is removed per hour. Fuel consumed for drying coconut halves for 1.6m^3/min airflow rate was 21 kg coconut husk. 4.46 kg coconut husk is utilized to remove 1 kg of water from coconut halves during drying from initial moisture content 42.52 per cent to 5.58 per cent final moisture content. 5 kg of copra got from drying of 11.88 kg coconut halves in 21 hours drying period. Fig. 4.21 shows moisture content behaviour during 21 hour drying period for 1.6 m^3/min airflow rate. It is observed that average moisture removed per hour for whole drying period found more for 1.4 m^3/min airflow rate as compared to other airflow rates (0.0 m^3/min airflow rate, 1.2 m^3/min airflow rate, 1.6m^3/min airflow rate). Fig 4.22 shows moisture removal behaviour for 0.0 m^3/min airflow rate, 1.2 m^3/min airflow rate, 1.4 m^3/min airflow rate, and 1.6 m^3/min airflow rate.

4.3.4 Quality of copra

Quality of copra dried by using airflow rates 0.0 m^3/min(control reading), 1.2m^3/min, 1.4 m^3/min and 1.6m^3/min were evaluated by three parameters colour, protein and fat of copra. Colour of copra were decided from L, a, b values measured by colorflex instrument which are given in Appendix A19, Appendix A20, Appendix A21 and Appendix A22. Copra was graded in two grades one is white copra and second is brown copra. Influence of airflow rate on data on colour of copra is shown in Table 4.17

Table 4.17 Colour analysis of copra

Airflow rate	Colour of copra	
m^3/min	**%**	**%**
	White copra	Brown copra
Control (0.0)	60	40
1.2	61.25	38.75
1.4	71.62	28.37
1.6	71.42	28.57

It is observed that per cent of white copra was found more at 1.4 m^3/min airflow rate as compared to control (0.0 m^3/min) .1.2 m^3/min, 1.6 m^3/min airflow rate.

Protein estimation was done by Kjeldahil method by AOAC (1970). The data for protein value is given in Appendix A23. Protein values of copra are tabulated in Table 4.18

Table 4.18 Protein analysis of copra

Airflow rate	Protein	
m^3/min	%	%
	White copra	Brown copra
Control (0.0)	5.56	5.50
1.2	5.83	5.81
1.4	6.10	6.15
1.6	5.83	5.81

Using 0.0m^3/min airflow rate average protein found was 5.53 per cent. Average protein found was 5.82 per cent for 1.2m^3/min airflow rate. Average protein found was 6.12 per cent for 1.4m^3/min airflow rate. Average protein found was 5.82 percent for 1.6m3/min airflow rate.

Fat estimation was done by Soxhlet apparatus method by AOAC (1970). The fat percentage given in Appendix A24. Fat value of copra is shown in Table 4.19

Table 4.19 Fat analysis of copra

Airflow rate	Fat	
M^3/min	%	%
	White copra	Brown copra
Control (0.0)	58.67	56.67
1.2	58	56
1.4	58.67	56
1.6	56	53..33

Average fat found was 57.67 per cent for control (0.0m^3/min airflow rate). Using 1.2 m^3/min, 1.4 m^3/min airflow rate average fat found was 57 per cent.57.33 per cent respectively. Average fat found was 55 per cent for 1.6 m^3/min airflow rate.

The considering parameters Colour, protein, fat and moisture content of copra, the colour of the copra should white for good copra quality with 6 per cent final moisture content of copra. Good quality of copra gives 60-62 per cent fat while 6-7 per cent protein. The modified CAET Dapoli copra dryer gave on an average 72 per cent white copra, 57 per cent fat and 6 per cent protein.

4.3.5 Performance of modified CAET Dapoli copra dryer

Modified CAET Dapoli copra dryer was tested for fuel consumption, drying capacity, drying temperature, heat generated heat utilized, heat loss, moisture removal and quality of material dried. The modified CAET Dapoli copra dryer were tested for three airflow rates in the range of 1.2m^3/min 1.4m^3/min and 1.6m^3/min in which drying done for control (0.0 m^3/min airflow rate) means dryer tested for without operating blower. Observations of H.U.F. and C.O.P. were recorded and are given in Appendix A25 and Appendix A26 for airflow rates 0.0 m^3/min and 1.2 m^3/min, respectively while Appendix A27 and Appendix A28 for airflow rates 1.4m^3/min and 1.6 m^3/min, respectively.

It was found that in batch drying of copra H.U.F. less than unity. The amount of heat utilized goes on decreasing with increase exhaust air temperature with time. As H.U.F. increases drying efficiency increases. It was also found that the small value of C.O.P. at the beginning of the experiment and then increases rapidly after certain time due to rise of exhaust air temperature.

Testing of modified CAET Dapoli copra dryer were observed that using 0.0 m^3/min airflow rate 15.85 kg coconut halves took 32 hours for drying to removed 5633 g of water from initial moisture content 52.71 per cent to final moisture content 4.81per cent. It required 18 kg coconut husk as fuel for drying of 15.85 kg of coconut halves. On an average 176.03 g of water is removed per hour for 0.0 m^3/min airflow rate. For 1.2 m3/min airflow rate 12.85 kg coconut halves took 29 hours for drying to removed 5272 g of water from initial moisture content 49.99 per cent to final moisture content 5.11 per cent with 20 kg fuel consumption. On an average 182 g of water is removed per hour for 1.2 m^3/min airflow rate. Using 1.4m^3/min airflow rate 8114 g of water removed in 30 hours from initial moisture content 56.46per cent to final moisture content 6.62 per cent. It consumed 25 kg fuel for drying 15.19 kg coconut halves. On an average 271 g of water is removed per hour for 1.4 m^3/min airflow rate. Using 1.6m^3/min airflow rate 11.88 kg coconut halves took 21hours for drying to remove 4731 g of water from initial moisture content 42.52 per cent to final moisture content 5.58per cent. It required 21 kg coconut husk as fuel for drying of 11.88 kg of coconut halves. On an average 226 g of water is removed per hour for 1.6 m^3/min airflow rate. On an average 4 kg coconut husk required to remove 1 kg of water from coconut halves for this dryer.

It is observed that average moisture removed per hour for whole drying period found more (271g) for 1.4m^3/min airflow rate as compared to other airflow rates (0.0m^3/min airflow rate, 1.2m^3/min airflow rate, 1.6m^3/min airflow rate). On an average 8000 g water removed in 30 hours drying period from initial moisture content 50 per cent to 6 per cent final moisture content It indicates that two times more moisture removal capacity found for modified CAET Dapoli copra dryer as compared to CAET Dapoli copra dryer. On an average 20 kg coconut halves required for drying of 15 kg coconut halves from initial moisture content 50 per cent to 6per cent final moisture content which is relatively cheaper as compared to CAET

Dapoli copra dryer. Fuel chamber of the dryer is having small volume space ($0.08m^3$) as compared to CAET Dapoli copra dryer. It is observed that 150 W heat loss through heating chamber wall is relatively small as compared to CAET Dapoli copra dryer. Total spaced required for dryer unit is 0.81 m^2 which is 3-4 times less as compared to CAET Dapoli copra dryer which is easy in transportation.

Performance of both dryer were tested and presented in Table 4.20

Table: 4.20 Comparison between CAET Dapoli developed copra dryer and modified CAET Dapoli copra dryer

Sr. No.	Parameter	CAET Dapoli developed copra dryer	Modified CAET Dapoli copra dryer	Remarks
1	Capacity of dryer (single layer)	6-8 kg coconut halves / batch	15-16 kg coconut halves / batch	Drying capacity of modified CAET copra dryer is 2 times higher than CAET developed copra dryer
2	Fuel consumption	110-120 kg. for drying of 8 kg coconut halves	20-30 kg. for drying of 16kg coconut halves	Modified CAET copra dryer saves in fuel by 6 times over the CAET developed copra dryer
3	Heat loss	1500W	150W	Modified CAET copra dryer saves in heat energy by 10 times (1000 W) over the CAET developed copra dryer.
4	Moisture removed per hour	134 g	267 g	Modified CAET copra dryer has 2 times higher moisture removes than CAET developed copra dryer.
5	Quality of copra White copra, per cent	52 -55	60– 72	Modified CAET copra dryer improves 15 per cent quality of copra over the CAET copra dryer.
6	Housing space for dryer unit	3m^2	0.81m^2	Modified CAET copra dryer saves on space is 2.19 m^2 and easy for movement and transportation over the CAET Dapoli developed copra dryer. It means 70%-75% saving in space

V. SUMMARY AND CONCLUSIONS

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. Copra drying in Konkan region is practiced largely through sun drying during the summer season and chula drying during rainy season which has its own demerits while use of mechanical copra dryer in Konkan region is very scarce. Konkan region has more than 100 rainy days of the year with average rainfall of 3000mm (40–140 mm/hour) and sun drying for coconuts harvested in rainy season is impossible. There is a need to have a small mechanical indirect batch type dryer suited to the requirement of Konkan farmers. The Department of Agricultural Process Engineering of Dr. BSKKV Dapoli has developed batch type, indirect force convection copra dryer.

The CAET Dapoli developed a small-scale copra dryer was tested for its drying performance by conducting two airflow rates (airflow rate 1.4 m^3/min and second at 1.6 m^3/min airflow rate). It was tested for fuel consumption, drying capacity, drying temperature, heat generated, heat utilized, heat loss, moisture removal and quality of material dried. During testing it is observed that on an average 30 kg of coconut husk required as fuel to remove 1 kg of water from coconut halves from initial moisture content of 50 per cent to final moisture content of 6 per cent. It indicates that dryer required relatively more quantity of fuel to remove the moisture. Fuel chamber of the dryer is also having large volume space (0.28 m^3). Also convection of heat from heating chamber to drying chamber through one single pipe limits the utilization of available heat energy in the heating chamber and thereby prevents the use of available heat energy. It is observed that 40-45 per cent heat is lost (1500 W) through heating chamber walls due to lack of insulation. Total spaced required for dryer unit is 3 m^2 that create difficulty in transportation. The CAET copra dryer was modified to make simple, compact, portable and efficient drying.

Modified CAET Dapoli copra dryer works on the principle of indirect heating (forced convection and natural convection). The components of the new modified CAET Dapoli copra dryer are drying chamber housing with two trays, heating chamber, chimney and blower. The modified CAET Dapoli developed copra dryer was tested for its performance of drying in respect of drying capacity, fuel consumption, heat loss, temperature distribution in drying chamber, quality of dried copra using three airflow rates (1.2 m^3/min, 1.4 m^3/min, 1.6 m^3/min airflow rates)

The conclusions drawn from the current study are as follows,

1) CAET Dapoli developed copra dryer consume s 120 kg of fuel (coconut husk) to dry a batch of 8 kg coconut halves from initial moisture content 50 per cent to 6 per cent final moisture content in 30 hours drying period however, modified CAET copra dryer consume 20 kg of fuel (coconut husk) to dry 16 kg coconut halves from initial moisture content 50 per cent to 6 per cent final moisture content in 30 hours drying period.
2) CAET Dapoli developed copra dryer occupied a total space of 3 m^2 for drying and heating chamber and is inconvenient for its movement and transportation however, modified CAET copra dryer occupied a total space of 0.81 m^2 for drying and heating chamber and is provided with castor wheel for easy movement and transportation. Modified CAET Dapoli copra dryer saving on space is 2.19 m^2 over the CAET Dapoli developed copra dryer.
3) CAET Dapoli developed copra dryer has a tremendous loss of heat (1500 W) from heating chamber walls to atmosphere due to lack of insulation however, modified CAET copra dryer has a heat loss from heating chamber walls to atmosphere of about 150 W which 10 times less than the CAET Dapoli developed copra dryer.
4) CAET Dapoli developed copra dryer removed 4000 g of moisture from a batch of 8 kg coconut halves during drying from initial moisture content of 50 per cent to 6 per cent of final moisture content in 30 hours drying period however, modified CAET copra dryer removed 8000 g of moisture from batch of 16 kg coconut halves during drying from initial moisture content of 50 per cent to 6 per cent of final moisture content in 30 hours drying period.

CAET Dapoli developed copra dryer remove average 134 g moisture per hour of drying however, modified CAET copra dryer remove average 267 g moisture per hour of drying.

5) CAET Dapoli developed copra dryer renders 55 per cent of white copra after the drying operation however modified CAET copra dryer provides 72 per cent of white copra after the drying operation.
6) In the CAET developed copra dryer the use of blower is necessary to convey the heat from heating chamber to drying chamber however heat can be conveyed from heating chamber to drying chamber in the modified CAET copra dryer without the use of the blower. Modified CAET copra dryer can be used by indirect natural convection batch type method.

Modified CAET copra dryer has 2 times higher moisture removal rate than CAET developed copra dryer. Modified CAET copra dryer saves fuel (coconut husk) 6 times over CAET developed copra dryer also drying capacity two times greater than the CAET developed copra dryer. Modified CAET copra dryer to retain the heat energy 10 times (1000 W) over the CAET developed copra dryer. Modified CAET copra dryer is providing efficient drying and has large drying capacity and potential fuel saving ability also use with natural and force convection indirect batch type method.

Future Suggestions for future work.

- Capacity of dryer could be increased by increasing the capacity of drying chamber (one more layer of coconut halves).

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