

PERMANENT REFERENCE

DESIGN AND DEVELOPMENT OF AN IMPROVED SOLAR HYBRID DRYING
TECHNIQUE FOR SMALL SCALE QUALITY COPRA PROCESSING

by



THIRUCHELVAM THANARAJ

Thesis
submitted in partial fulfilment of the requirements
for the degree of

MASTER OF PHILOSOPHY



Thesis
Library - EUSL

in the

57609

POSTGRADUATE INSTITUTE OF AGRICULTURE

of the

UNIVERSITY OF PERDENIYA,
PERADENIYA

AUGUST, 2004

PROCESSED
Main Library, EUSL

(PB)
bb5'355'072
THA

ABSTRACT

Copra is an intermediate product in processing coconut oil. The objective of making copra is to stabilize the coconut kernel against microbiological attack and spoilage by reducing its moisture content to below 6%.

The objective of this study was to design and develop an appropriate solar hybrid drying technique to produce good quality white copra for small holders. White copra is produced in indirect type dryers in large scale or in kilns using charcoal. However, the cost of production in both methods is high. A new solar hybrid dryer was designed to avoid the high costs.

The solar collector, furnace and heat exchanger were evaluated separately for their performances. The efficiency of the solar collector was very low and only 4%. Solar energy was incorporated in the drying process whenever it was available. The maximum temperature raised in the solar collector was around 50 °C. Since the temperature raise was not enough to maintain the drying temperature of 60 °C, furnace energy was also incorporated at the paddy husk feeding rate of 3 kg/h.

The temperature in the drying chamber was increased up to 43 °C during the evaluation of furnace at the feeding rate of 3 kg/h and the furnace efficiency was around 43%. At the feeding rate of 5 kg/h, the temperature increase in the drying chamber was 53 °C and the furnace efficiency was 48%. Since these feeding rates were not enough to maintain the drying temperature, the third evaluation was conducted at the feeding rate of 10 kg/h. The internal temperature increased to 62 °C

in the drying chamber and the furnace efficiency was 70%. The average temperature of the furnace outlet air was recorded as 206 °C.

The final moisture content of 7% was obtained in the copra dried in the solar hybrid dryer. The dried copra was graded in to 73% white copra, 21% Milling Ordinary Grade -II (M O G-II) and the balance 6% as M O G-III (dusty copra). About 70 hours of continuous drying was needed to complete the drying process at the thermal efficiency of 10%.

The final moisture content of copra dried in the CRI copra kiln was 8% and the copra was graded as 82% M O G-I and the rest of 18% was M O G-III (burnt copra). White copra was not produced in the kiln drying. The average temperature recorded at the drying bed was 75 °C, and it took 62 hours to complete the drying process at the thermal efficiency of 16%.

The final moisture content of copra dried under direct sun was 10% and copra was graded as 25% white copra, 56% M O G-II and the balance 20% as M O G-III copra (mouldy cups). In order to bring down the initial moisture content from about 50% to 10%, it was necessary to dry copra for continuous 6 days at the thermal efficiency of 23%. Therefore, further drying is necessary to bring down the moisture to the safe moisture content of 6%.

Out of the three methods tested, solar hybrid drying was found to be the most economical technique for copra processing under local conditions.

2.6	DESORPTION AND ADSORPTION ISOTHERMS	11
2.7	MECHANISM OF DRYING	11
2.7.1	Surface evaporation of moisture	12
2.7.2	Internal migration of moisture	12
2.7.3	Drying rates	13
2.8	EFFICIENCY OF DRYING	14
2.9	BASIC PRINCIPLES OF COPRA DRYING	14
2.10	DIFFERENT TECHNIQUES USED IN COPRA DRYING	15
2.10.1	Direct drying	15
2.10.2	Indirect drying	19
2.10.3	Sun drying	22
2.10.4	Solar drying	24
2.11	SOLAR ENERGY AND ITS UTILIZATION	26
2.11.1	Potential of solar drying	27
2.11.2	Solar collectors	27
2.11.3	Flat plate collector (FPC)	28
2.11.3.1	Common types of flat plate collectors	29
2.11.4	Classification of solar dryers	31
2.11.4.1	Whether or not the drying commodity is exposed to insolation	31
2.11.4.2	The mode of air flow through the dryer	31
2.11.4.3	The temperature of the air circulated to the drying chamber	32

2.11.5	Selection of dryer types	32
2.11.5.1	Direct dryers employing natural convection with a combined solar collector and drying chamber	32
2.11.5.2	Direct dryers employing natural convection with a separate solar collector and drying chamber	33
2.11.5.3	Indirect dryers employing forced convection with a separate solar collector and drying chamber	34
2.11.5.4	Indirect dryer employing natural convection with separate collector and drying chamber	34
2.11.6	Hybrid dryers	35
2.12	COCONUT OIL	37
2.12.1	Coconut oil expelling	37
2.12.2	Chemical and physical properties of coconut oil	37
2.13	QUALITY PARAMETERS	38
2.13.1	Aflatoxin in coconut products	38
2.13.2	Polycyclic aromatic hydrocarbons (PAH)	41
2.13.2.1	PAH and carcinogenicity	41
2.13.2.2	Presence and removal of PAH in coconut products	42
2.14	GRADING SYSTEM OF COPRA	43
2.14.1	Copra classification standards in Philippines, India and Papua New Guinea	45

2.14.1.1	Quality standard for copra in the Philippines: classes of copra (Based on method of drying and appearance)	45
2.14.1.2	Grades of copra used in the Philippines (based on moisture content)	46
2.15	FURACE	46
2.15.1	Types of furnaces	46
2.15.1.1	Tunnel furnace	48
2.15.1.2	Modified underfeed stoker	48
2.15.1.3	Modified underfeed stoker for wood firing	49
2.15.1.4	Cylindrical furnace	50
2.15.1.5	Ceylon Tobacco Company type furnace	50
2.15.1.6	Traditional type furnace	50
2.15.1.7	Integrated furnace/heat exchanger units	51
2.16	CHIMNEY AND DRAUGHT	51

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1	OVEN DRYING OF COCONUT	54
3.2	DESIGN OF THE SOLAR HYBRID DRYER	54
3.2.1	Design of the drying chamber	54
3.2.2	Design of the solar collector	57
3.2.2.1	Estimation of the projected area of the solar collector	58

3.2.2.2	Estimation of the slope of the collector	58
3.2.3	Fabrication of the heat exchanger	60
3.2.3.1	Estimation of area of the heat exchanger	60
3.2.4	Design of the step grate furnace	61
(a)	Design of the hopper	62
(b)	Design of the fire tube	63
3.2.4.1	Estimation of the feeding rate	64
3.2.5	Design of the chimney	64
3.2.6	Design of the base stand and downloading mechanism	65
3.2.7	Design of the solar reflector	66
3.2.8	Design of the flexible roof	67
3.3	CRI-IMPROVED CEYLON COPRA KILN DRYING	70
Fire pit		72
Drying platform		72
3.4	SUN DRYING	73
3.5	INSTRUMENTATION	74
3.6	SAMPLING OF COCONUT FOR EXPERIMENT	76
3.7	DETERMINATION OF MOISTURE CONTENT	77
3.8	GRADING OF COPRA	77
3.9	TESTING AND EVALUATION OF THE SOLAR HYBRID DRYER	77
3.9.1	Evaluation of the solar collector	77
3.9.1.1	Estimation of the efficiency of the solar collector	78
3.9.2	Evaluation of the step grate furnace	79

3.9.2.1 Evaluation of the efficiency of the furnace	80
3.9.3 Evaluation of the heat exchanger	81
3.9.3.1 Evaluation of the efficiency of the heat exchanger	81
3.9.4 Testing of the solar hybrid drying technique	82
3.9.4.1 Estimation of the drying efficiency in solar hybrid drying	83
3.10 TESTING AND EVALUATION OF THE CRI IMPROVED COPRA KILN	84
3.10.1 Estimation of thermal efficiency	86
3.11 SUN DRYING OF COCONUTS	86
3.11.1 Estimation of drying efficiency	87
3.12 ECONOMIC ANALYSIS OF THE SYSTEMS	87

CHAPTER 4

4.0 RESULTS AND DISCUSSION	
4.1 DRYING CHARACTERISTICS OF COCONUT	89
4.1.1 Continuous drying	89
4.1.2 Intermittent drying	90
4.2 EVALUATION OF THE SOLAR COLLECTOR	92
4.2.1 The efficiency of the cylindrical solar collector	92
4.3 EVALUATION OF THE STEP GRATE FURNACE	93
4.3.1 Evaluation of furnace at the husk feeding rate of 3 kg/h	93
4.3.2 Evaluation of furnace at the husk feeding rate of 5 kg/h	95
4.3.3 Evaluation of furnace at the feeding rate of 10 kg/h	96

4.4 EVALUATION OF HEAT EXCHANGER	99
4.4.1 The overall efficiency of the heat exchanger	100
4.5 TESTING OF THE SOLAR HYBRID DRYER	100
4.5.1 The variation of temperature in the drying chamber	102
4.5.2 The relative humidity in the drying chamber	103
4.5.3 The solar insolation	105
4.5.4 The drying characteristics of coconut with time	106
4.5.5 Drying efficiency	107
4.5.6 Copra grades	107
4.6 TESTING OF THE CRI IMPROVED COPRA KILN	109
4.6.1 The temperature distribution at the drying bed	109
4.6.2 The behaviour of relative humidity (RH)	112
4.6.3 The solar insolation and drying rate of copra during the initial sun drying	113
4.6.4 The removal of moisture during kiln drying	114
4.6.5 Thermal efficiency of the kiln drying	115
4.6.6 Grade of copra	116
4.7 SUN DRYING OF COCONUTS	117
4.7.1 The surface temperature of drying cups	118
4.7.2 Climatic parameters during the drying period	119
4.7.3 Drying characteristics of coconut under sun	120
4.7.4 Drying efficiency of coconut	122
4.7.5 Copra quality	123