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Appendix A

Table A1: Manufacture of copra, coconut oil in Sri Lanka (CDA statistics)

Year	Copra (MT)	Coconut Oil (MT)
1975	203082	120263
1976	162818	100196
1977	79885	49160
1978	130145	80089
1979	163145	100397
1980	101619	62535
1981	125083	75668
1982	170397	102485
1983	138408	82884
1984	62295	36824
1985	218456	129807
1986	242616	143300
1987	125372	71622
1988	61987	34548
1989	129528	74633
1990	127806	74804
1991	60568	32556
1992	54956	30219
1993	40685	22000
1994	103985	60000
1995	112643	64515
1996	74468	41000
1997	67348	36185
1998	70272	38000
1999	64602	36000
2000	82062	44407
2001	112996	64320
2002	59033	30100
2003	49466	21000
2004	37081	25000
2005	37419	20000

Table A2: Edible oil consumption pattern in Sri Lanka (Peiris, T. S. G., n.d.)

Year	CNO (MT)	Non-CNO (MT)	Rate of oil consumption (Bottle/person/year)		
			CNO	Non-CNO	Both
1989	44965	21000	4.11	1.92	6.03
1990	62580	19712	5.66	1.78	7.44
1991	31507	27231	2.81	2.43	5.23
1992	30234	40012	2.67	3.53	6.20
1993	48800	42235	4.253	3.68	7.94
1994	56121	55276	4.83	4.75	9.58
1995	55562	36965	4.71	3.14	7.85
1996	38688	73461	3.25	6.16	9.41
1997	50915	85023	4.22	7.04	11.26
1998	35498	90498	2.91	7.42	10.32
1999	31503	117284	2.55	9.48	12.02
2000	39751	90079	3.16	7.16	10.32
2001	61106	72662	5.02	5.97	10.99
2002	52896	142480	4.28	11.53	15.81
2003	82613	119502	6.60	9.55	16.15
2004	1 26105	111699	2.06	8.82	10.88

Appendix B

Table B1: Characteristics of coconut oil

Characteristic	Edible type						Non edible type	Method of Test
	Refined, bleached and deodorized coconut oil	Refined and bleached coconut oil	White coconut oil	Coconut oil	Paring coconut oil	Virgin coconut oil	Industrial coconut oil	
Colour 25-mm cell on the Lovibond colour scale expressed in Y+5R, not deeper than	2	2	4	5	5	1	11	SLS 313
Relative density at 30°C/30°C	0.915 to 0.920	0.915 to 0.920	0.915 to 0.920	0.915 to 0.920	0.915 to 0.920	0.915 to 0.920	0.915 to 0.920	
Relative density at 40°C	1.448 to 1.4492	1.448 to 1.4492	1.448 to 1.4492	1.448 to 1.4492	1.448 to 1.4492	1.448 to 1.4492	1.448 to 1.4492	
Moisture & other matter Volatile at 105°C, max.	0.1	0.1	0.4	0.4	0.4	0.5	0.5	
Insoluble impurities, per Cent by mass, max	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Free fatty acids, as lauric Acid, per cent by mass	0.1(max.)	0.1(max.)	0.8(max.)	0.8(max.)	0.8(max.)	0.2(max.)	1.0 to 5.0(or as traded)	
Iodine value	7.5 to 9.5	7.5 to 9.5	7.5 to 11.0	7.5 to 11.0	9.0 to 18.0	6.0 to 11.0	7.5 to 18.0	
Saponification value	255(min.)	255(min.)	248 to 264	248 to 264	248 to 264	255(min.)	248 to 264	
Unsaponifiable marrer, per cent by mass, max	0.5	0.8	0.8	0.8	0.8	0.2	0.8	
Mineral acidity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	

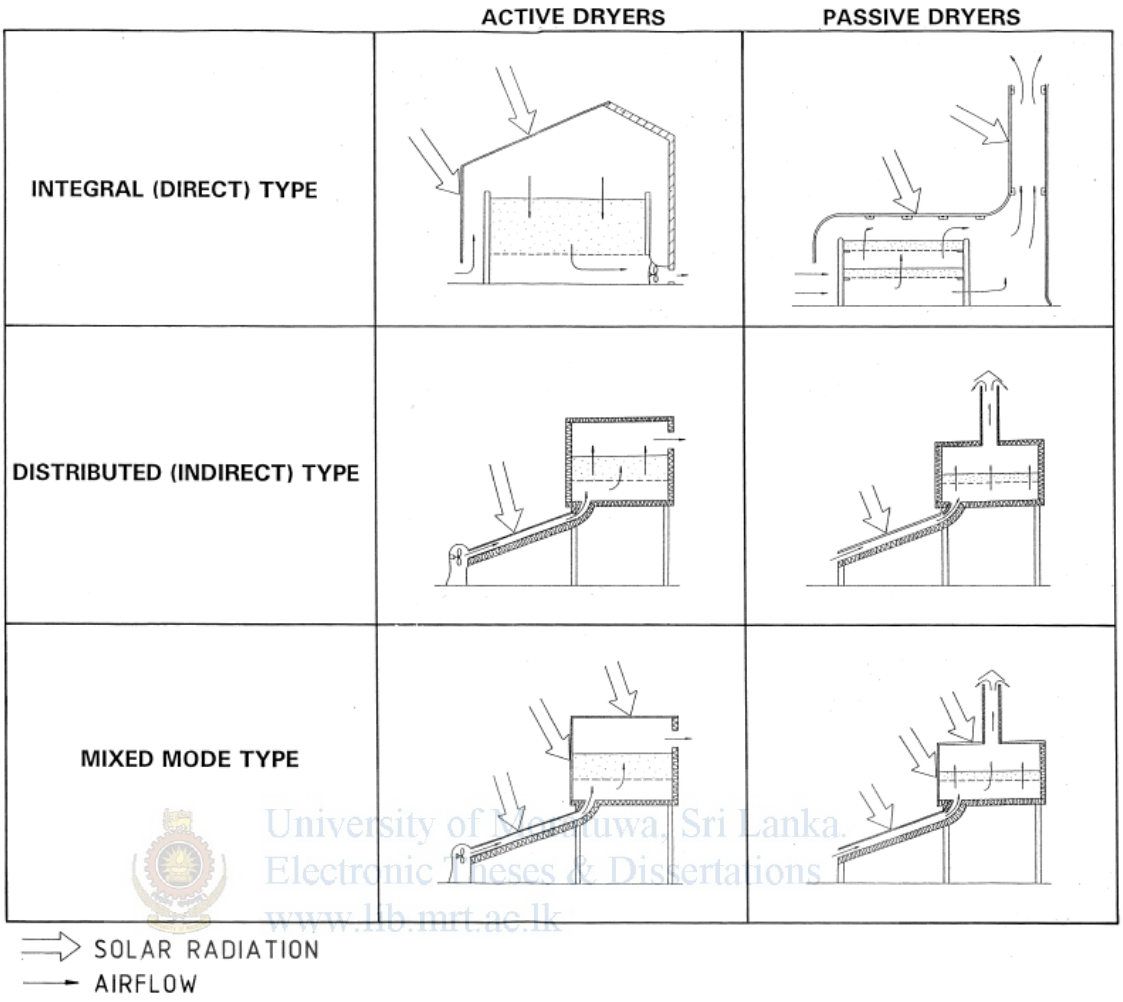

Figure B1Typical solar energy drier designs

(Ekechukwua, O.V. and Nortonb, B., 1999)

Appendix C

1. Details of equipments

Equipment	Model Name	Technical Details
Luxmeter	Testo 545	Range 0-100000 lux Resolution :1 lux (0-32000 lux) Resolution : 10 lux (0-100000 lux
Velometer	Alnor	Range of pressure = 0 to 10 inches H2O Resolution: = 0.01 inches H2O Range of flow rate: = 0-10000 ft/min Resolution: = 20 ft/min
Oven	Griffin 1/200	Range of temperature = 0℃ to 200 ℃

(Luxmeter)

(Velometer)

(Oven)

2. Soxhelt Extraction of Coconut Oil

Procedure:

1. Apply a thin layer of grease at all the ground glass joints.
2. Weigh 10 grams of scraped coconut accurately in to the extraction thimble.
3. Introduce 300 ml of solvent to the distillation flask.
4. Fit the condenser on top of the extractor tube, and circulate water.
5. Start heating the flask. Reflux the solvent for about an hour (4 to 5 times).
6. Switch off the heating and allow it to cool. Then remove the thimble from the extractor tube and fit the apparatus back. Distill the solvent to the extractor tube and collect it for reuse. Then weigh the oil left behind in the flask.

Results:

Represent the oil content by weigh percentage on the basis of the scraped coconut used in the experiment.

$$Oil\ Content = \frac{Amount\ of\ oil\ extracted}{Weight\ of\ coconut} \times 100$$

3. Tests of coconut oil

1. Free Fatty Acid (FFA) content

This test measure the free fatty acid content by a titration with ethonolic KOH and gives the value as a percentage. FFA % is defined as the number of KOH required to neutralize the free fatty acid in 1g of oil. The content of free fatty acid is increased due to the moisture and sunlight and therefore can be reduced if refrigerated.

Chemicals :

- NaOH or KOH solution – for RBD oil, refined oil and white oil normality of the solution should be 0.1. For industrial oil solution it should be 0.5 N.
- Phenolphthalein indicator

- Ethanol, 95% (V/V), neutral to the phenolphthalein indicator

Testing procedure :

- Correctly weigh out 40g of RBD coconut oil or refined oil (if it is white coconut oil the mass is 20g and if it is industrial oil mass is 10g) to a 250 ml conical flask.
- Add 50ml of the solvent (solvent consists of equal amounts of ethanol and petroleum ether)
- Heat it on a water bath
- Titrate the mixer with 0.1 $moldm^{-3}$ KOH solution using phenolphthalein as the indicator
- Take the end point of the titration as the colorless oil solution turnes to pink color and take the reading.
- The FFA percentage can be measured using the formula given below.

$$FFA\% = (V * N * 20.0 / (W)$$

Where,

V= Volume of the KOH obtained from the titration

N = Normality of the KOH (OH^- ion concentration – here N = 0.1)

W = Weight of the oil sample (25 g)

2. Iodine value

Iodine value is defined as the number of grams of Iodine which react with 100g of coconut oil. The Iodine value measures the quantity of unsaturated fatty acid by a titration method. The unsaturattion is due to the presence of double bonds. Higher the iodine value indicates that there are more unsaturated fatty acids present in the oil.

Testing Procedure (Wij's Method):

- 2 – 2.5 grams of oil is mixed with 15 ml CCL_4 to dissolve the fatty acid on CCL_4 in an iodine flask.

- Then the solution is treated with an 20 ml of Wij's iodine solution and seal the bottle. Wij's iodine solution is a solution of iodine monochloride (ICl) in glacial acetic acid. (Pale yellow color solution)
- Allow the bottle to stand for 30 minutes in dark.
- Next 15 ml of potassium iodide solution and 100 ml of distilled water is added. Unreacted iodine monochloride is reacted with potassium iodide which converts it to iodine.
- This is immediately titrated against 0.1 M sodium thiosulfate solution using phenolphthalein as the indicator. The color change from pale yellow to colorless.
- Add 3 ml of starch. Then the solution turns in to dark blue color.
- The iodine concentration is then determined by titration with sodium thiosulfate
- At the end point the color changes from blue to colourless.
- 1 ml of 0.1 M sodium thiosulfate solution = 0.01269 g of iodine.
- The difference between a control titration and the titration with the fat present multiplied by this factor gives the mass of iodine absorbed by the oil.
- The iodine value can be calculated by the given equation

$$Iodine\ Value = \frac{(mL\ of\ blank - mL\ of\ sample) \times N(sodium\ thiosulfate) \times 12.69}{Weight\ of\ sample\ (g)}$$

3. Saponification value

This is the number of KOH needed to neutralize the fatty acids formed by the complete hydrolysis of 1gram of the lipid. This method is used to determine the total acid content, both free and combined, of coconut oil. The combined acids are

primarily esters formed by reaction with the neutral components present in the original oil.

Chemicals:

- KOH 0.5 N solution in 95% ethanol.
- 0.5 N HCl solution
- Phenolphthalein indicator

Procedure:

- Weigh 2 g of oil sample, to the nearest 0.01 g, into a 500ml clean, dry, flat bottomed flask.
- Add 25 ml of 0.5 N ethanolic potassium hydroxide by using a pipette.
- Boil continuously under a Reflux condenser for 60 minutes.
- Titrate between 60 and 70ºC with 0.5 N HCl acid using phenolphthalein indicator
- Run a blank in the same manner.

Calculation :

Saponification Value ={ (A - B) x N x 56.1} / W

Where,

A = HCl volume, for blank in mL

B = HCl volume, for sample in mL

W = weight of sample (dry basis), g

N = normality of HCl solution

56.1 = weight of potassium hydroxide

4. Relative Density

Relative density is the density of the oil with respect to the water at the temperature of 30^{o}C. It is measured by using a 50 ml density bottle.

Procedure :

- Weigh out the dry empty density bottle with stopper correctly to four decimel places. (W1 g)
- Cool or heat the oil until the temperature of the oil reaches 30 ^{o}C.
- Then fill the bottle with coconut oil and measure the weight (W2 g). the filling must be done slowly and carefully while holding the bottle in a slanting position where the air bubbles are not not taken in with the oil. the froth produced by the ar bubbles are carefully removed and the stopper is carefully inserted before measuring the weight.
- The relative density is given by the following equation

$$\text{Relative density} = (W2 - W1) / 50$$

Since 50 ml density bottle is taken the weight of the water that can be filled to the density bottle is equalent to 50 g.

5. Color

Color of coconut oil is measured by using a Lovibond Tintometer in 25 mm cell. Lovibond Tintometer is an automatic instrument and is very easy to use,. There is no need to build up calibration curves as they are already established in the instrument. The menu system guides operators through the selection of operating parameters. Thereafter, measurements are initiated by just a single key press and take less than 25 seconds to complete.

6. Refractive Index

Refractive index of coconut oil is the ratio between the velocities of the life of a definite wave length in vacuum to the velocity in the oil medium. Refractive index is measured using a refractometer.

Procedure :

- Calibrate the refractometer and its accuracy using liquids with knowing refractive index.

- Filter the oil sample through filter paper to remove any impurities and the last traces of moisture. The sample must be completely dry.
- Make certain that the temperature of the refractometer is 40.0°C
- Fill the space between the prisms of the refractometer completely with oil. Close the prisms and tighten firmly with a screw head.
- Allow to stand for 3 minutes so that the sample comes to the temperature of the instrument.
- Adjust the instrument and light to obtain the most distinct reading possible and then determine the refractive index. Take the readings in a temperature of nearly 40.0°C.
- Take several readings and calculate the average of all. After each determination, the prisms of the instrument should be cleaned with a cotton wool soaked with a mixer of ether and dry alcohol.

The refractive index at any other temperature can be calculated from the equation given below.

$R' = R + 0.0036 * T$ (For temperatures higher than 40.0°C)

$R' = R - 0.0036 * T$ (For temperatures lower than 40.0°C)

Here R' = refractive index at a different temperature

R = refractive index at 40.0°C

T = temperature difference in °C

7. Moisture

The moisture content of the oil can be measured by either oven method or using a moisture balance. In the oven method a sample of oil is placed in an oven and heated to 101 – 105 °C and the loss of mass due to the vaporization is calculated.

In the moisture balance method the sample is placed on a moisture balance for 5 – 10 minutes. Then the balance in the instrument is balanced by adjusting the weights thereby the moisture content can be directly obtained.

8. Mineral acidity

Mineral acidity measures the contents of mineral such as HCL and H2SO4 acids mixed with oil.

Chemicals:

- NaOH or KOH solution
- Light petroleum (Boiling point 40°C – 60°C)
- Methyl orange indicater

Test Procedure:

- 50g of oil is accurately weighed to a separating funnel
- The oil is washed 3 times from portions of 50 – 60 ml of hot distilled water.
- The hot water washings were combined to another separating funnel.
- The water was allowed to be cooled to the room temperature.
- The traces of fatty acids were removed by allowing it to be extracted to 50ml of light petroleum.
- The wash water was separated out and titrate with 0.01N NaOH or KOH solution using methyl orange as the indicater.

Mineral Acidity = 100 * V / m

Here V = titration volume of NaOH or KOH in ml, m = mass of the oil taken in grams

Here the mineral acidity is obtained as milliliters of 0.01 N acids per 100 grams of oil.

9. Unsaponifiable Matter

This measures the other contents in coconut oil such as proteins, carbohydrates, alcohol, sterol etc.

Chemicals:

- 95% Ethanol
- Ethonolic KOH solution
- Diethyl Ether (relative density 0.72 – 0.724)
- HCl acid (relative density .1.6 – 1.18)

- 0.5N KOH solution
- Phenolphthalein indicater
- Acetone
- 0.1N Ehanolic NaOH solution

Procedure:

- 2 – 2.2 grams of oil is accurately weighed and transferred to a 250ml flask.
- 25ml of Ehanolic NaOH solution was added and to the oil and heated and refluxed with frequent swirling on a boiling water bath for 1 hour
- The ethonolic soap solution was transferred to a separating funnel and rinsed with 50ml of water for several times.
- Allowed to be cooled to the room temperature.
- Flask is rinsed with 50ml of ether and transferred to the separating funnel.
- Separating funnel is stoppard and shake vigorously.
- The solution was allowed to be separated and clarified.
- The lower aqueous ehtanolic solution was transferred to a flask.
- The ethereal extract was poured from the top of the separating funnel in to a second 250ml separating funnel which contain 20ml of water..
- The aqueous ehtanolic solution was transferred to the first separating funnel from the flask. The extraction was repeated twice using 50ml of ether while adding the extracted ether layer to the second separating funnel..
- If a filter has been used, the filter was also washd with ether and added to the second separating funnel
- The liquid in the second separating funnel was swirled without shaking and allowed to be separated and the lower aqueous layer was discarded.
- The ethereal layer was washed out twice using further 20ml of water portions and discarding the lower aqueous layer.
- 20ml of 0.5N KOH solution was added to the ethereal solution and was shake vigorously. It was allowed to be separated and the aqueous layer was removed. Same procedure was followed using 20ml water.

- The washing with alkali and then with water was followed more for two times.
- The washing with water was continued until the residue water become neutral to the phenolphthalein indicator.
- Ethereal solution was transferred to a weighed flask and most of the ether was distilled off.
- 2 – 3 ml of acetone was added and the removal of the solvent was continued
- The flask was then dried out until a constant mass was obtained. The temperature must not exceed 80°C.
- The residue was dissolved in 10ml of freshly boiled and neutralized ethanol and it was titrated with 0.1N ethonolic NaOH using phenolphthalein as indicator.
- If the volume of 0.1N ethonolic NaOH required is less than 0.1ml, the mass of the residue can be taken as the mass of Unsaponifiable matter.
- If the volume exceeds 0.1ml the test have to be rejected and repeated.

The Unsaponifiable matter % by mass = $(M_1/M_0) * 100$

Here, M_1 = mass of residue in grams

M_0 = mass of oil taken in grams

10. Insoluble impurities

Insoluble impurities are defined as the dirt and other foreign matter insoluble in light petroleum. It is expressed as a percentage by mass.

Procedure :

- A weifhed quantity of 20ml – 50ml of oil at a temperature below 60^{o}C is filtered through an ashless open texture filter paper which was previously dried in an oven at 105 ^{o}C and weighed in a stoppered weighing bottle.
- If the oil is slow in filtering the oil has to be dialuted in light petroleum (the boiling point of the petroleum should be between 40 ^{o}C – 60 ^{o}C) before filtration

- In a continuous extraction apparatus, the filter paper containing impurities is extracted using light petroleum.
- After a complete extraction, the filter paper and the contents are dried in an oven at 98 ^{o}C - 100 ^{o}C and was reweighed in a stoppered weighing bottle until the mass is constant.

Total impurities % by mass = (M3 – M2) / M1 * 100

Here,

M1 = mass of oil taken in grams

M2 = mass of weighing bottle and the dry filter paper in grams

M3 = mass of weighing bottle and the dry filter paper containing impurities in grams

For all the above mentioned tests there is a Sri Lankan Standard (SLS) which express the critical value. The table below indicates those critical values of refined bleached deodorized oil, refined bleacied oil, white coconut oil, paring oil, virgin coconut oil and the industrial coconut oil.

Appendix D

1. Calculation of thermal efficiency

Colorific value of firewood	= 14700 KJ/kg
Calorific value of coconut shell	= 12900 KJ/kg
Capacity of blower	= 0.746 Kw
Latent heat of vaporization of water	= 2270 kJ/kg

a) Experiment 1 (Multi bed experiment)

Compartment 1

Amount of final dried product at the (m_f)	= 11.94 kg
Initial moisture content of coconut (M_0)	= 49.13 %
Final moisture content of coconut (M_f)	= 6.6 %
Oil content of copra	= 11.94 × (1- 0.066)
	= 11.152 kg
Initial weight of coconut without shells	= 11.152 × 1/ (1-0.4913)
	= 21.922 kg
Weight loss during drying	= 21.922 - 11.94
	= 9.982 kg

Compartment 2

Amount of final dried product at the (m_f)	= 12.11 kg
Initial moisture content of coconut (M_0)	= 48.62 %
Final moisture content of coconut (M_f)	= 6.91 %
Oil content of copra	= 12.11 × (1- 0.0691)
	= 11.273 kg
Initial weight of coconut without shells	= 11.273 × 1/ (1-0.462)
	= 21.941 kg
Weight loss during drying	= 21.941 – 12.11
	= 9.831 kg

Compartment 3

Amount of final dried product at the (m_f)	= 12.37 kg
Initial moisture content of coconut (M_0)	= 48.82 %
Final moisture content of coconut (M_f)	= 7.11 %
Oil content of copra	= 12.37 × (1- 0.071)
	= 11.49 kg
Initial weight of coconut without shells	= 11.49 × 1/ (1-0.4882)
	= 22.451 kg
Weight loss during drying	= 22.451 – 12.37
	= 10.081 kg
Initial Surface moisture in coconut halves	= 7.12 kg
Total weight loss during drying	= 37.006 kg
Amount of energy used to evaporate the moisture	= 37.006 × 2270 kJ
	= 84003.62 kJ

Amount of firewood used for drying coconut	= 51 kg
Amount of coconut shells used for drying coconut	= 25 kg
Amount of energy supplied by biomass	= 51 × 14700 + 25 × 12900
	= 1072200 kJ
Number of operating hours of the blower	= 45
Energy consumed by the blower	= 45 × 0.746 × 3600
	= 120852 kJ
Total energy utilized for drying of coconut	= 1072200 + 120852
	= 1193052 kJ
Thermal efficiency of the drier	= (84003.62 / 1193052) × 100
	= **7.07 %**

b) Experiment 2 (Single bed experiment)

Amount of final dried product at the (m_f)	= 12.06 kg
Initial moisture content of coconut (M_0)	= 49.81 %

Final moisture content of coconut (M_f)	= 7.00 %
Oil content of copra	= 12.06 × (1- 0.070)
	= 11.216 kg
Initial weight of coconut without shells	= 11.216 × 1/ (1-0.4981)
	= 22.347 kg
Weight loss during drying	= 22.347 – 12.06
	= 10.287 kg
Initial Surface moisture in coconut halves	= 2. 192 kg
Total weight loss during drying	= 12.479 kg
Amount of energy used to evaporate the moisture	= 12.479 × 2270 kJ
	= 28327.33 kJ
Amount of firewood used for drying coconut	= 34 kg
Amount of coconut shells used for drying coconut	= 8 kg
Amount of energy supplied by biomass	= 34 × 14700 + 8 × 12900
	= 603000 kJ
Number of operating hours of the blower	= 37
Energy consumed by the blower	= 37 × 0.746 × 3600
	= 99367.2 kJ
Total energy utilized for drying of coconut	= 603000 + 99367.2
	= 702367.2 kJ
Thermal efficiency of the drier	= (28327.33 / 702367.2) × 100
	= **4.05 %**

c) Experiment 3 (Single bed experiment)

Amount of final dried product at the (m_f)	= 12.24 kg
Initial moisture content of coconut (M_0)	= 50.41 %
Final moisture content of coconut (M_f)	= 6.75 %
Oil content of copra	= 12.24 × (1- 0.0675)
	= 11.414 kg

Initial weight of coconut without shells	= 11.414 × 1/ (1-0.5041)
	= 23.016 kg
Weight loss during drying	= 23.016 – 12.24
	= 10.776 kg
Initial Surface moisture in coconut halves	= 2. 370 kg
Total weight loss during drying	= 13.146 kg
Amount of energy used to evaporate the moisture	= 13.146 × 2270 kJ
	= 29841.42kJ
Amount of firewood used for drying coconut	= 36 kg
Amount of coconut shells used for drying coconut	= 8 kg
Amount of energy supplied by biomass	= 36 × 14700 + 8 × 12900
	= 632400 kJ
Number of operating hours of the blower	= 35
Energy consumed by the blower	= 35 × 0.746 × 3600
	= 93996 kJ
Total energy utilized for drying of coconut	= 632400 + 93996
	= 726396 kJ
Thermal efficiency of the drier	= (29841.42/ 726396) × 100
	= **4.18 %**

2. Calculation of Specific moisture evaporation rate (SMER)

a) Experiment 1 (Multi bed experiment)

Amount of water evaporated from the drying of coconut	= 37.006 kg
Amount of energy utilized for the drying of coconut	= 1193052 kJ
SMER	= 1193052 kJ / 37.006 kg
	= 32.11 GJ/kg

b) Experiment 2 (Single bed experiment)

Amount of water evaporated from the drying of coconut	= 12.479 kg
Amount of energy utilized for the drying of coconut	= 702367.2kJ
SMER	= 702367.2 / 12.479 kg
	= 55.99 GJ/kg

c) Experiment 3 (Single bed experiment)

Amount of water evaporated from the drying of coconut	= 13.146 kg
Amount of energy utilized for the drying of coconut	= 726396 kJ
SMER	= 726396 / 13.146 kg
	= 54.27 GJ/kg