COCONUT SHELL BIOMASS GASIFICATION WITH WASTE HEAT RECOVERY TECHNOLOGY TO DRY PULVERIZED KERNEL FOR VIRGIN COCONUT OIL EXTRACTION

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Abstract

In this study, a dryer with a waste heat recovery unit, using coconut shells as the base material for gasification was compared with electric and kerosene dryers in terms of drying curve pattern, rate of dying, cost of drying and quality of fresh dried pulverized kernel under the dry processing method of virgin coconut oil production. Dried pulverized kernel samples from each dryer were tested for basic quality parameters, taking desiccated coconut samples as the control according to Sri Lankan standards. Storability of dried pulverized kernel samples was carried out by taking desiccated coconut samples as the control under the standard packaging material. Basic quality parameters of charcoal obtained from the gasifier were tested with charcoal made using pit method as the control according to Sri Lankan standards.

The basic quality was same in all fresh dried pulverized kernel samples. Aerobic plate counts of fresh dried pulverized kernel samples exceeded the critical limit. During storage, moisture absorption was same in all samples while free fatty acid content and aerobic plate count of dried pulverized kernel samples were greater than desiccated coconut. Quality parameters of all charcoal samples were within the standard limits except particle size of charcoal made using the gasifier. Coconut shell biomass gasification with waste heat recovery technology can be used in dry processing method of virgin coconut oil production as a renewable, low cost and environmental friendly energy alternative and to minimize the drawbacks of pit method of charcoal production.

Keywords: Coconut shell charcoal, Desiccated coconut, Dried pulverized kernel, Virgin coconut oil, Waste heat recovery technology

1. Introduction

Virgin coconut oil (VCO) is a unique product of coconut (*Cocos nucifera* L.). VCO may be defined as the naturally processed, chemically free and additive free product from fresh coconut kernel or its derivative (coconut milk and coconut residue) which has not undergone any further chemical processing after extraction. It is the purest form of coconut oil and contains natural vitamin E (Silveira *et al*., 2004). Due to an up surging market segment for VCO, there is a growing interest for VCO production.

VCO can be produced by wet, intermediate moisture content and dry processing methods. Although, both wet and intermediate moisture content methods are operationally simple and require low capital investment, their output capacity is not sufficient for a medium scale operation. Secondly, in both these processing methods, occurrence of higher moisture has to be expelled from the oil by means of a heat treatment, which ultimately leads some discoloration of the final product, which is disadvantageous (Balawan and Chapman, 2006).

An alternative dry processing method could overcome the above mentioned drawbacks effectively. In this method, coconut kernel has to be pulverized to the category of particles medium in size and then dehydrated at 60 ^{0}C until the moisture content reaches 2–3% (Asanka *et al*., 2008). Commercially available mechanical dryers can be used to dry pulverized kernel. But these mechanical dryers are very expensive and mostly operated by electricity or fuel oils for hot air generation hence, their operation costs are very high.

Biomass gasification can be used for hot air generation purposes in coconut processing sector as a renewable, low cost and environmental friendly energy alternative. It can be defined as the partial oxidation of a solid fuel which produces a combustible gas (Kutz *et al*., 1983). In this process, a solid biomass is converted into a high quality gaseous fuel which can be further burnt to generate heat.

Coconut shell has a great potential to be used as the base material for gasification. In Sri Lanka, coconut shell is used for charcoal and the traditional charcoal production is done by pit firing. The traditional pit method of production has a charcoal yield of 25–30% of the dry weight of shells used. The charcoal produced by this method is of variable quality, and often contaminated with extraneous matter and soil. The smoke evolved from pit method is not only a nuisance but also a health hazard. In view of this, the operation of the traditional pit is either restricted or not permitted at all in several areas in Sri Lanka to prevent environmental pollution and to minimize health hazards to people (Breag and Joseph, 1989).

Coconut shell biomass gasification with waste heat recovery unit (WHU) as developed virtually eliminates the smoke problem associated with the traditional pit method of charcoal production and simultaneously enables the heat generated during the process normally lost to the surroundings to be used in associated heat exchanger systems in the coconut industry. The WHU has a chamber in which coconut shells are converted to charcoal and the gas evolved during the process is subsequently burnt in a furnace/heat exchanger system to provide process heat. WHU both maximizes the utilization of shell feedstock for charcoal production and gives the processor a greater degree of self–sufficiency.

This study was to conduct field test trials to evaluate the suitability of coconut shell biomass gasification with WHU to dry pulverized kernel for VCO in terms of drying curve pattern, cost of drying and physical, chemical and microbial quality parameters of dried pulverized kernel (DPK).

Other than drying, it is also important to store DPK under proper storage conditions to produce quality VCO. Therefore, as a secondary objective of this study, suitability of standard packaging material for desiccated coconut (DC) to prolong the quality of DPK was tested.

2. Materials And Methods

2.1. Location

The study was conducted at the Coconut Processing Research Division of the Coconut Research Institute, Lunuwila, Sri Lanka during the period of March to July, 2009.

2.2. Materials

Fully matured seasoned coconuts were collected from the Bandirippuwa estate of the Coconut Research Institute. Samples of medium size desiccated coconut were purchased from Badhuwaththa mills Katana. Coconut shell charcoal samples by pit method were purchased from Kirimatiyana area.

2.3. Preparation of Dried Pulverized Kernel

A batch of coconuts were de-husked and de-shelled to get wet kernel. After peeling-off the brown testa, the white kernel was split-open to remove water. Spilt-halved kernels were broken manually into pieces and fed into locally fabricated pin-cutter to pulverize into medium size kernel particles.

2.4. Dehydration of Pulverized Kernel

Performance of a dryer with WHU, an electric dryer and a kerosene dryer was evaluated for drying pulverized kernel.

2.5. Dryer with WHU

The dryer was an indirect heated tray type oven. Drying chamber and WHU were major components of the dryer with WHU. A gasifier having a thermal output of 60 Kw and a feeding capacity of 16-20 Kg/hr of crushed coconut shells was used in WHU. Crushed coconut shells with 10% moisture and 2-2.5 inches particle size were required as the fuel. The gasifier was possible to yield 20% (w/w) of charcoal output.

Partial burning of coconut shell could produce a combustible gas. Ash particles in the producer gas were needed to be removed by a cyclone separator. Producer gas coming out from the cyclone separator was passed into a gas burner. The flue gas coming out from the burner was colorless and satisfying the requirements for environmental pollution control. The heat generated from the flame was blown into the drying chamber using an electric blower via a heat exchanger.

2.6. Electric Dryer

The dryer was a direct heated tray type oven, consisted of a drying chamber, heating elements, a power driven fan and an exhaust fan, equipped with facilities to adjust the temperature and pressure.

2.7. Kerosene Dryer

The dyer was an indirect heated tray type oven. Drying chamber and hot air generator were two major components of the dryer. Hot air generator was a kerosene burner. The directly heated air by the burner was blown into the drying chamber via a heat exchanger, using an electric blower.

2.8. Determination of the Drying curve

The wet pulverized kernel particles were spread uniformly, 1-2 inches in trays of each dryer up to the dryer's maximum capacity. The maximum drying capacities were pulverized kernel of 500, 300 and 500 nuts in dryer with WHU, electric dryer and kerosene dryer respectively. The drying process was carried out at 60 ^{0}C. The contents of the trays were turned over at the middle of the drying process to ensure uniformity of drying of particles.

During drying, pulverized kernel samples were drawn from each dyer at 30 minutes intervals till completion of drying. Moisture contents of the samples were measured using a moisture analyzer at 105 ^{0}C.

2.9. Oil Extraction

Crude coconut oil was extracted from fresh DPK by using an electric oil expeller machine.

2.10. Determining the Basic Quality Parameters of DPK and Desiccated Coconut Samples

Fresh DPK and DC samples with particles medium in size (SLS 98;1988) were tested for oil content, Free Fatty Acid (FFA) content, limit of discoloration and aerobic plate count according to SLS 98 (1988). Moisture Content (MC) was determined using a moisture analyzer at 105 ^{0}C.

2.11. Shelf Life Studies

Fresh DPK and DC samples (250g) with particles, medium in size (SLS 98;1988) containing average MC of 2% were sealed in bags (SLS 98;1988) 30 cm x 30 cm in size and tested for MC, FFA and aerobic plate count once in two weeks for a period of three months according to SLS 98 (1988).

2.12. Determining Quality of Charcoal

Charcoal made using the gasifier and pit method were tested for contaminants, moisture, particle size, volatile matter content, ash content and fixed carbon content according to SLS 571 (1982).

2.13. Statistical Analysis

Analysis of variance was carried out to find out significant differences among samples using Statistical Analyzed System (SAS).

3. Results And Discussion

3.1. Drying and Drying Rate Curves of Pulverized Kernel for Three Dryers

Initial moisture content of fresh pulverized kernel was about 49% (Figure 1). Moisture content gradually reduced in three dryers. But times taken to reduce the moisture content below 2% were 480, 300 and 150 minutes in electric dryer, dryer with WHU and kerosene dryer respectively (Figure 1).

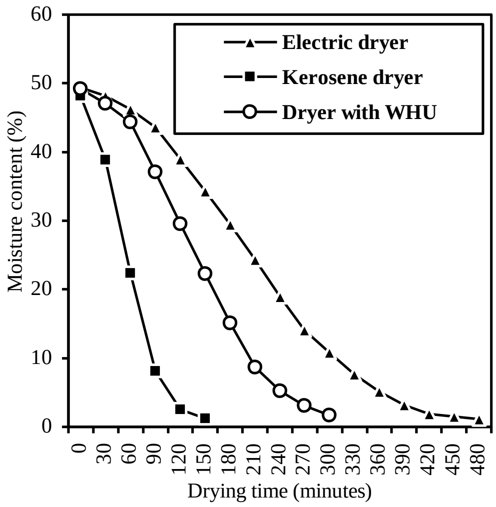

Figure 1. Drying curves of pulverized kernel for three dryers at 60 ^{0}C

The drying rate of kerosene dryer increased rapidly reaching a maximum of 0.55 gmin^{-1} drying rate and decreased in the same manner, while in the dryer with WHU and electric dryer, drying rate increased gradually and reached a plateau at 90 and 120 min respectively, then decreased gradually until drying time 300 and 480 min respectively (Figure 2).

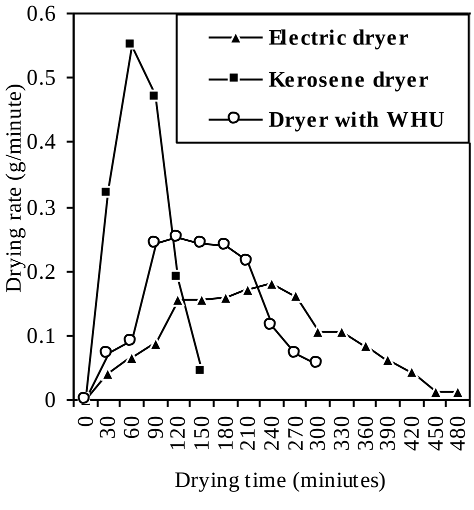

Figure 2. Drying rate curves of pulverized kernel for three dryers at 60 ^{0}C

3.2. Basic Quality Parameters of Fresh DPK from each Dryer and DC

Table 1. Basic Quality Parameters of Fresh DPK from each Dryer and DC

Means in the same column bearing different letters represent the significant difference at $P < 0.05$, [1]Each value in the table represents the mean of duplicate analysis, APC-Aerobic Plate Count, CFU-Colony Forming Units

The initial analysis of moisture, FFA, oil content and aerobic plate count are given in Table 1. In DC, the FFA and aerobic plate count were significantly lower than DPK samples from each dryer. All the samples from three dryers and the control (DC) were within the standard limit in terms of limit of discoloration (Table 2).

Table 2. Limit of discoloration of fresh DPK and DC

Sample	*Limit of discoloration*		
	Yellow	*Red*	*Blue*
DPK-Electric dryer	*0.7*	*0.2*	*Nill*
DPK-Kerosene dryer	*0.7*	*0.2*	*Nill*
DPK-Dryer with WHU	*0.7*	*0.2*	*Nill*
DC	*0.4*	*0.1*	*Nill*
SLS 98:1988	*< 0.9*	*< 0.2*	*< 0.1*

Sample	*Moisture (%)*	*Oil (%)*	*FFA (%)*	*APC (CFU/g)*
DPK - Electric dryer	*2.00 a*	*69.49 a*	*0.15 a*	$2.5 * 10^5$ *a*
DPK - Kerosene dryer	*2.01 a*	*69.48 a*	*0.16 a*	$2.4 * 10^5$ *a*
DPK - Dryer with WHU	*2.00 a*	*69.38 a*	*0.15 a*	$2.5 * 10^5$ *a*
DC	*1.99 a*	*69.54 a*	*0.06 b*	$5.2 * 10^2$ *b*
SLS 98:1988	*< 3*	*> 68*	*< 0.3*	$< 1 * 10^5$

3.3. Moisture Content Variation of the Samples during Storage

Although the samples were packed in standard five ply bags, the samples absorbed moisture during the storage period (Table 3). The standard five ply bags made inner low density polyethylene lining of 85µm thickness and an outer five tier bag are not completely impermeable to moisture (Samarajeewa and Illeperuma, 1985). According to SLS 177 (1991), MC should not exceed 3% (w/w). In this study both DPK and DC were found to exceed this limit within the tenth week of storage.

Table 3. Variation of Moisture Content of DPK and DC during storage[1]

Week	*Moisture (%)*	
	DPK	*DC*
0	*1.99*	*1.99*
2	*2.23*	*2.21*
4	*2.38*	*2.38*

6	*2.61*	*2.62*
8	*2.85*	*2.81*
10	*3.06*	*3.02*
12	*3.33*	*3.27*

[1]Each value in the table represents the mean of duplicate analysis

3.4. Free Fatty Acid Content Variation of Samples during Storage

FFAs are produced by enzymatic breakdown of coconut oil in the presence of water. The enzymes responsible are present in both the coconut and contaminating bacteria and fungi. According to SLS 98 (1988), the acidity should not exceed 0.3% of free fatty acids calculated as lauric acid. In this study, the FFA of DPK was found to exceed this limit within the fourth week of storage, while FFA of DC was within the recommended limit during the period of 12 weeks (Table 4).

Table 4. Variation of FFA content of DPK and DC during storage[1]

Week	*FFA (%)*	
	DPK	*DC*
0	*0.15*	*0.06*
2	*0.27*	*0.07*
4	*0.34*	*0.07*
6	*0.47*	*0.07*
8	*0.60*	*0.08*
10	*0.77*	*0.08*
12	*0.91*	*0.08*

[1]Each value in the table represents the mean of duplicate analysis

3.5. Variation of Aerobic Plate Count of Samples during Storage

Generally, coconut either in dry or wet form is a good nutrient medium for microbial growth. Hence, sanitary precautions are necessary during processing to ensure longer shelf life of coconut products. When DC and DPK stored at ambient temperature conditions, microorganisms can multiply by taking nutrients. According to SLS 98 (1988), aerobic plate count could not exceed the range 10^4 to 10^5. DC was able to remain within this limit all throughout 12 weeks of storage. However, the aerobic plate count of DPK exceeded the critical limit from the onset of the experiment and it was higher than desiccated coconut during the period of storage (Table 5).

Table 5. Estimated number of Aerobic Plate count in DPK and DC during storage[1]

Week	*Aerobic Plate Count (CFU/g)*	
	DPK	*DC*
0	$2.6*10^5$	$5.2*10^2$
2	$3.9*10^5$	$1.7*10^3$
4	$9.3*10^5$	$3.4*10^3$

6	*4.8*10^{6}	*5.1*10^{3}
8	*5.2*10^{6}	*4.1*10^{4}
10	*2.8*10^{7}	*5.6*10^{4}
12	*4.0*10^{7}	*6.9*10^{4}

[1]Each value in the table represents the mean of duplicate analysis, CFU-Colony Forming Units

The reason for having a higher aerobic plate count in DPK samples than DC, could be poor hygienic practices prevailed in the processing of DPK. Contaminants could also be possible due to microbial population remaining in the equipment used for paring, splitting, and pulverizing of the kernel. Also, the possibility of contamination by human hands cannot be ruled out. In DC manufacturing better precautions are adopted to prevent the invasion of microbes at various stages of processing. The use of chlorinated water and hot water dipping are two important practices adopted to bring down the microbial load of the wet kernel. Apart from this, steam sterilization is used at different point of the production line to prevent contaminations (Anon. 2002).

3.6. Basic Quality Parameters of Charcoal Made using Pit Method and Gasifier

The quality parameters of two types of charcoal are given in Table 6. Except the particle size of charcoal made using the gasifier, all other parameters were within the standard limits (SLS 571:1982). Usage of crushed coconut shells for gasification process and pressure generated by the vertical charcoal bed on charcoal particles, at the bottom level of the gasifier would be major reasons for this.

3.7. Cost Calculation

Table 7 shows the cost of production (COP) for each dryer for producing DPK of 1000 nuts. The lowest COP was obtained by kerosene dryer while the highest was obtained in electric dryer.

Table 6. Contaminants, Particle size, Moisture content, volatile matter content, Ash content and Fixed carbon content of charcoal made using pit method and gasifier

Method	*Cont. (%)*	*Size (%)*	*MC (%)*	*VMC (%)*	*AC (%)*	*FFC (%)*
Pit	*0.37*	*2.34*	*7.11*	*17.65*	*1.75*	*80.60*
Gasifier	*0.16*	*33.85*	*9.09*	*16.60*	*1.77*	*81.63*
SLS 571:1982	*< 2*	*< 5*	*< 10*	*< 20*	*< 2*	*> 79*

Cont.–Contaminants, MC-Moisture content, VMC-Volatile matter content, AC-Ash content, FCC-Fixed carbon content

Table 7. Cost of production for producing DPK of 1000 nuts using three dryers

Cost for preparing pulverized kernel of 1000 nuts			
Item		*Quantity*	*Value (Rs.)*
Coconuts (@ Rs. 12/nut)		*1000 nuts*	*12000.00*
Labor costs	*De-husking (@ Rs. 0.7/nut)*	*1000 nuts*	*700.00*
	De-shelling (@ Rs. 0.4/nut)	*1000 nuts*	*400.00*
	De-pairing (@ Rs. 0.4/nut)	*1000 nuts*	*400.00*
	Pulverizing (@ Rs.75/labor hour)	*3 hours*	*225.00*

Electricity for pulverizing (@ Rs. 10/unit)					2.17 units	21.73
Total cost for preparing pulverized kernel of 1000 nuts						13746.73
Cost of drying pulverized kernel of 1000 nuts using dryer with WHU, Electric dryer and Kerosene dryer						
Item	Dryer					
	Dryer with WHU		Electric dryer		Kerosene dryer	
	Quantity	Value (Rs.)	Quantity	Value (Rs.)	Quantity	Value (Rs.)
Labor cost for drying (@ Rs. 75/ labor hour)	18 labor hours	1350.00	40 labor hours	3000.00	12 labor hours	900.00
Electricity (@ Rs. 10/ unit)	94.3 units	943.00	241.87 units	2418.67	9.27 units	92.72
Kerosene oil (@ 50.20/ Liter)					16.45 Liters	825.66
Coconut shells (@ Rs. 6/ Kg)	200 Kg	1200.00				
Total cost for drying		3493.00		5418.67		1818.38
Income from selling by products when producing DPK of 1000 nuts						
Item					Quantity	Value
Coconut husk (@ Rs. 1/ husk)					1000 husks	1000.00
Coconut shells (@ Rs. 6/ Kg)					160 Kg	960.00
Dry pairings (@ Rs. 50/ Kg)					30 Kg	1500.00
Charcoal (@ Rs. 35/ Kg)					40 Kg	1400.00
Cost of producing DPK of 1000 nuts using dryer with WHU, Electric dyer & Kerosene dryer						
Cost of production	Dryer with WHU		Electric dryer		Kerosene dryer	
*	12379.73		15705.40		12105.11	
**	100.66		127.70		98.42	

However, considering pollution and environmental effect, the dryer with WHU would be a better option. Moreover, the dryer with WHU produced charcoal as a byproduct, which would give an extra income.

4. Conclusions

Coconut shell biomass gasification with WHU can be used to dry pulverized kernel as a renewable, low cost and environmental friendly energy alternative and to minimize the drawbacks of traditional pit method of charcoal production. By implementing more powerful blower in the dryer with WHU, drying capacity can be further increased. Thereby, the drying cost can be reduced. The exhaust air coming out from the heat exchanger system of the dryer with WHU had a temperature of 230-250 ^{0}C. Thus, it can be further improved to be used in dehydration processes. Long term storage of DPK would be not advisable for quality VCO production.

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