Engineering an Improved Coconut Processing System in the Philippines at the Farm-Level

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Abstract—**The traditional methods of copra processing such as sun-drying and smoke-drying are still generally implemented in the Philippines by coconut manufacturers. These methods produce aflatoxin and polycyclic aromatic hydrocarbon (PAH) in copra and crude coconut oil (CNO) that resulted to very low prices of copra-related products in the world market. This research aims to improve the quality of the products of the Philippine coconut manufacturing industries by employing modern design engineering and technology to coconut processing that would develop high-value exportable coconut products. The Wijose Process of coconut processing developed for the production of copra, milk and dietary flour resulted to 94.7% recovery of the coconut fruit parts and waste materials. Seven mathematical models were examined to describe the drying behavior of coconut meat slices at 60, 70 and 80°C. The modified combined decomposition model (MCDM) gave the best fit with high coefficient of determination value. Solid fuel was produced by torrefaction from dried coconut leaves that significantly improved its heating value compared to that of the untreated biomass. A coconut processing plant was developed based on the conceptual design of the Wijose Process.**

***Index Terms*—aflatoxin, coconut oil (CNO), copra, copra cake, torrefaction, Wijose Process**

I. INTRODUCTION

The coconut palm [*Cocos nucifera* L.] is an important fruit tree in the world, providing food for millions of people, especially in the tropical and subtropical regions, and with its many uses it is often called the "tree of life". Export earnings from the coconut industry consistently registered the highest among that of all other agricultural commodities. Copra and its derivative, CNO are the traditional major export products from the Philippine coconut industry.

Recently, however, its market has declined and has constantly been threatened due to varied domestic and international marketing problems as well as prevailing/changing conditions. The coconut production process in the Philippines does not involve innovative technology. Hence, the products are usually of low quality that resulted to very low prices of copra-related products in the world market.

A. Copra

In the coconut industry, drying the coconut meat reduces its moisture content that inhibits the growth of bacteria and the action of enzymes that causes spoilage. The coconut meat is named copra once drying starts. Well-dried copra contains 7% moisture and is processed into coconut oil (CNO) and copra cake after storage when the moisture content is reduced to about 4-5%, the equilibrium moisture content of copra at most existing storage conditions [1]. In the Philippines, copra is mainly produced by small coconut holders using sun-drying or smoke-kiln methods.

B. Sun-Drying

The nut is split and dried under the sun for 5 days to achieve 7% moisture content. Sun-drying copra leads initially to bacterial damage, and later to attack by moulds and insects, the most harmful of which is the yellow-green mould called *Aspergillus flavus* and other aflatoxin-related moulds. Once moulding has started, moisture can accumulate and the mould might spread throughout the bulk [2].

Aftatoxins are most potent carcinogens in animal and human populations [3] and interfere with the functioning of the immune system [4]. Aflatoxins in copra cake, fed to animals, can be passed on in milk or meat, leading to human illnesses.

C. Smoke-Kiln Drying or "Tapahan"

The direct smoke dryer or "tapahan" is commonly used by coconut farmers in many coconut producing countries in the world. The smoke dryer has a grill platform usually of split bamboo where the halved nuts in the shell are placed. Copra produced from this dryer is usually dark, smells of smoke, at times scorched and has lower grade. "Tapahan" introduces an additional quality problem, contamination by polycyclic aromatic hydrocarbon (PAH) produced by incomplete combustion. Some PAH are

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highly carcinogenic. Among them benzo [*a*] pyrene, B[*a*] P and dibenzo [*a,h*] anthracene, B[*a,h*] P that are present in smoke-cured foods [5], [6].

D. Philippine Regulatory Action in food

International food safety standards set the limit of aflatoxin contamination at 20 parts per billion (ppb). PAH at 25 ppb. Due to stringent regulations on aflatoxin level imposed by legislation in the European Community (EC) in 1973, the Philippine Coconut Authority (PCA) set up an aflatoxin laboratory for the purpose of monitoring. The government is aiming at reducing aflatoxin and PAH levels in copra and in crude coconut oil. However any scheme must provide a real financial incentive to cover the increased processing costs necessary for the production of dry, mould-free copra [7]. To reduce the potential incidence of aflatoxin B_1 contamination to 5% of samples it will be necessary to dry to average marker levels of 4.6, 8.8 and 5.3% for kukum, tapahan and sun-dried copra respectively [8].

E. Wijose Process

Fig. 1 shows the process flow of the Wijose process that consists of the “dry” and “wet” processes. The Wijose wet process includes extraction of milk and the recovery of all the other parts of the coconut and its residues.

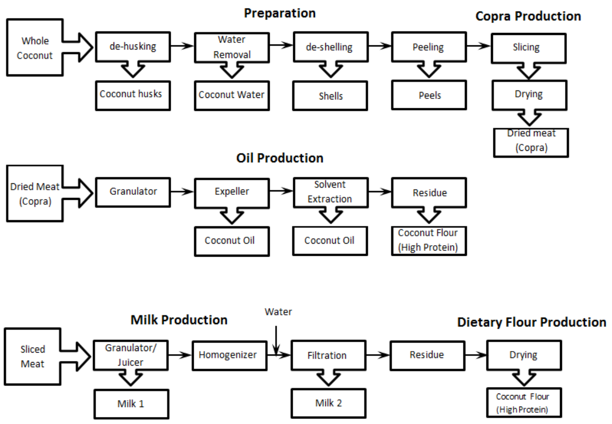


Figure 1. Process flow of the wijose process.

The Wijose dry process involves drying of coconut meat in a hot-air dryer that replaces the sun-drying and smoke-kiln methods. The hot-air dryer uses solid fuel produced by torrefaction utilizing coconut farm wastes, particularly, dried coconut leaves as an alternative source of energy for copra production.

F. Torrefaction

Torrefaction is a thermal method for the conversion of biomass operating in the low temperature range of 200 ℃-300 ℃, a kind of mild pyrolysis process that improves the fuel properties of biomass. It is carried out under atmospheric conditions in the absence of oxygen. Other names for the torrefaction process are roasting, slow- and mild pyrolysis, wood cooking and high temperature drying [9].

G. Design Engineering

Because engineers devise, build and create products, machines, structures, etc. for the benefit of mankind, they need design concepts. Design establishes and defines solutions to and pertinent structures for problems not solved before, or new solution to problems which have previously been solved in a different way. This is the essence of design engineering [10]. It involves a team of engineers from different engineering disciplines. Each discipline has its own specialized design applications demanded by their respective professions.

H. Conceptual Design

Conceptual design is the process by which the design is initiated, carried to the point of creating a number of possible solutions, and narrowed down to a single best concept. It is sometimes called the feasibility study. Conceptual design is the phase that requires the greatest creativity, involves the most certainty, and requires coordination among many functions in the business organization.

At the farm-level, copra processing is commonly practiced. On the average, about 91% of the coconut production of the Philippines during the period 1990-1997 passes through the copra stage. VCO is the natural oil obtained from fresh, mature kernel of the coconut by mechanical extraction. Coconut flour refers to the screened food-grade product obtained after drying, expelling and/or extracting most of the oil or milk from sound coconut meat.

This paper verifies the applicability of the Chemical Engineering design principles and concepts to the Wijose Process that employs modern design engineering and innovative technology that will improve the quality of products of the Philippine coconut manufacturing industries.

II. METHODS

A. Coconut Processing Practices and Technologies

Current copra processing practices of copra manufacturers and oil producers/exporters were gathered thru an online survey that will emphasize the necessity of the new coconut processing system.

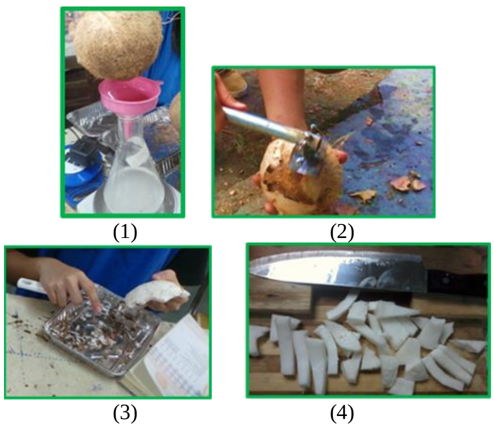


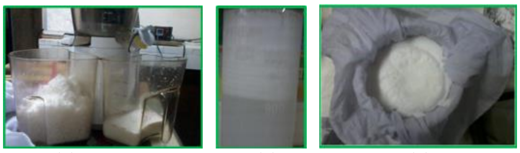
Figure 1. Preparation of coconut meat

B. Preparation of Coconut Meat

The preparation of coconut meat is identical for both wet and dry process. Ten matured nuts (9-12 months) were selected for the validation of the Wijose wet process in the laboratory scale. Fig. 2 shows the steps in the preparation of the coconut meat: (1) water removal; (2) de-shelling; (3) peeling of the seed coat; and (4) slicing of coconut meat. The husk, shell, peelings (or the seed coat) and coconut water were recovered.

C. Wijose Wet Process

The final stage of the Wijose wet process was executed as shown in Fig. 3: (1) the extraction of primary milk; (2) secondary milk extraction; and (3) recovery of coconut meat residue. The recovered coconut parts and waste materials were weighed using a precision balance with accuracy of 0.01g.



(1) (2) (3)

Figure 2. Execution of the wijose wet process

D. Wijose Dry Process

Single layers of thinly sliced coconut meat were heated at temperatures of 60-80 ℃ at 10 ℃ intervals every 30 minutes until constant weight was obtained using a laboratory dryer and a hot-air batch dryer (See Fig. 4) that was developed at the Chemical Engineering Laboratory at the University of the Philippines-Diliman. Weighing of air-dried coconut meat was done using a precision balance with an accuracy of 0.01g. Table I shows seven mathematical models (Newton, Page, Henderson and Pabis, logarithmic, non-linear decomposition model (NLDM) [11], combined decomposition model (CDM) and modified combined decomposition model (MCDM)) that were examined to describe the drying behavior of coconut meat slices at 60, 70 and 80°C.

Figure 3. The hot-air batch dryer

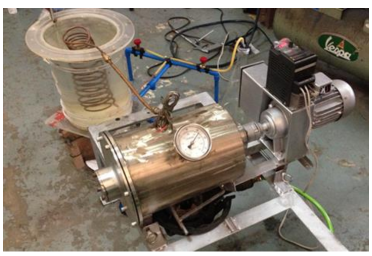


Figure 4. The experimental set-up for torrefaction batch process

TABLE I. THE EXAMINED MATHEMATICAL MODELS

Model	Name	References
MR = exp (-kt)	Newton	Liu&Bakker-Arkema (1997) Kingsly et al (2007) O'callaghan et al (1971)
MR = exp (-kt^n)	Page	Page (1949), Zhang and Litchfield (1991)
MR = a exp (-kt)	Henderson and Pabis (n=1)	Henderson & Pabis (1961) Chhinnman (1984)
MR = a exp (-kt) + C	Logarithmic	Yaldiz et al. (2001)
$MR=\left[\frac{A^{n-1}}{A^{n-1}kt(n-1)+1}\right]^{\frac{1}{n-1}}$	NLDM	Pestaño and Almajose, 2014
$MR=D\left[\frac{A^{n-1}}{(n-1)ktA^{n-1}+1}\right]^{\frac{1}{n-1}}+E(A\exp^{-kt})$	CDM	Pestaño and Almajose, 2014
$MR=D\left[\frac{A^{1-n}}{(n-1)ktA^{n-1}+1}\right]^{\frac{1}{n-1}}+E(A\exp^{-kt})$	MCDM	Pestaño and Almajose, 2014

E. Coconut Leaves Sample Production

Dried coconut leaves were collected in a coconut farm in Calauan, Laguna (CALABARZON, Region IV-A). The leaves were air dried and were cut into small pieces. Untorrefied biomass is indicated as "Raw".

F. The Torrefaction Experiment

Dried coconut leaves were torrefied using the lab-scale torrefaction batch reactor. Fig. 5 shows the experimental set-up of the torrefaction batch process. The reactor which is of rotary drum type was heated, at the rotating speed of the shaft of about 23 rpm.

Figure 5. Physical appearance of raw and torrefied biomass

When the desired reaction condition was reached, the set-up was allowed to cool; the solid product or the torrefied sample was weighed. Torrefied sample is indicated as "TS". Bomb calorimetry and proximate analysis were used in determining the physical and fuel properties of the torrefied sample. Fuel characteristics such as the heating value (HV), moisture content (MC), fixed carbon (FC) content and volatile matter (VM) of the "Raw" and "TS" were compared.

G. Conceptual Design

5000 nuts capacity per day, 8-hr operation per day with 1 hour downtime and 300 days operation per year were used as assumptions to develop a conceptual design of the overall Wijose process for the production of VCO and dietary flour applicable to a typical coconut community or farm in the Philippines.

III. Discussion

Eight out of 15 accredited Philippine Coconut Oil Producers Association (PCOPA) members responded to the on-line survey that emphasized on the manufacturing plant site, source of copra, the drying technology utilized by copra manufacturers.

It is noted that the plant sites of the 8 Oil Millers as well as their copra suppliers are located in the Wet Growing Zone (WGZ). In the Philippines, most coconut farms are situated in the WGZ that is highly suitable for rain fed coconut production year-round. The traditional methods of copra processing such as sun-drying and direct smoke drying are still generally implemented in the Philippines by the copra manufacturers. It is noted that the direct fired "tapahan" or the direct smoke drying is being utilized by all copra manufacturers mainly because smoke drying may be done even during wet season. It is known that PAH can be removed from coconut oil if the refining process includes treatment with suitable levels of activated carbon [5]. Sun-drying, the cheapest method of copra drying that requires sufficient sunlight, is favored by most copra manufacturers. Sun-drying requires no expenses for fuel. Fuel saved could mean additional farm income when sold or transformed into high value products like coconut shell charcoal, activated carbon, coir, etc. leading to the maximum utilization of farm resources.

The quality of copra and copra cake is influenced by the method and the manner of drying the coconut kernel. Improperly dried copra is vulnerable to fungal invasion largely by *Aspergillus flavus*, the fungus that produce toxic metabolites known as aflatoxin. On the other hand, it may contain PAH due to surface contact and smoke.

The Wijose Process of coconut processing was developed for the production of copra, milk and dietary flour offers solution to many problems besetting the industry with 94.7% recovery of the coconut fruit parts and waste materials. The Wijose wet process was carried out and validated in the lab scale for future implementation in the farm-level. The residuals of the coconut production (husk, shell, water, processing residues) can be converted to high value products. The coconut peel is a good source of vitamin E and the residue can be used as an animal feed additive.

The major products of the Wijose dry process are copra and clean white pressed cake. Copra can be sold to oil millers to produce high quality CNO. The cake residue can be processed as dietary flour, which is poised to become a major product of the coconut. Copra quality is based mainly on moisture content and appearance [12]. The Wijose process employs modern design engineering and innovative technology that will improve the quality of products of the Philippine coconut manufacturing industries.

TABLE II. Values of R2 For Batch Dried Coconut Meats

Hot-air dryer								
T, °C	Trial	Newton	Page	Henderson and Pabis	Log	NLDM	CDM	MCDM
60	1	0.778721	0.801083	0.988014	0.993932	0.999159	0.999173	0.999928
	2	0.764363	0.796013	0.992205	0.996575	0.999292	0.999614	0.999891
70	1	0.974216	0.977153	0.975649	0.987716	0.987716	0.999852	0.999853
	2	0.971061	0.977950	0.971409	0.991929	0.990043	0.999852	0.999852
80	1	0.675433	0.901503	0.889546	0.971528	0.999353	0.999921	0.999916
	2	0.714724	0.878871	0.941855	0.978053	0.998616	0.999807	0.999744
Laboratory dryer								
70	1	-0.105676	0.4691604	0.7372273	0.8772665	0.8822345	0.8825087	0.8843193

The hot-air dryer that was developed, produced high quality copra that is aflatoxin and PAH free. The MCDM gave the best fit with high coefficient of determination values (R^2=0.999916) compared to the other models that could adequately describe the drying characteristic of sliced coconut meat (See Table II).

Newton's iteration and the three-point stencil were used to determine the drying time for copra to reach a moisture content of 7%. The MCDM predicted the average drying time of 263.7 min. for the laboratory dryer and 188.3 min. for the hot-air batch dryer, the most effective drying temperature of copra is 80°C for both dryers.

In order to utilize dried coconut leaves in the coconut farm and to improve its biomass properties, solid fuel was produced by torrefaction from dried coconut leaves. Moisture content was reduced by an average of 61%. The HV was increased to 23 to 28 MJ/kg. The FC content increased from 10 to 46%. This means that torrefied biomass burns longer. The reduced O/C ratio makes the torrefied sample better suited for gasification. Volatile matter decreased from 74 to 42%. Gasification also produces less smoke since smoke producing volatiles are driven-off during torrefaction.

Fig. 6 shows the physical appearance of raw and torrefied biomass. Torrefaction process produces a solid uniform product that retained the shape and dimensions of the raw biomass.

A coconut processing plant for the production of VCO and dietary flour was developed in a coconut farm plantation in Lutucan I, Sariaya, Quezon Philippines based on the conceptual design of the Wijose process. The recommended drying area was then computed using Simpson's 1/3 Rule.

5000 nuts/day that is equivalent to 1890 kg meat/day will need a hot-air drying area of 3160 m^2 based on the conceptual design of the Wijose process applied to a typical coconut farm in the Philippines. 5000 whole matured nuts were able to produce 92.21 kg of dietary flour and 352.63 kg VCO. Fixed capital cost estimate at US$83,000 (Php 3.6 M).

IV. Conclusion

Despite the program, campaign and projects to resolve the possible threat of losing the European market for copra meal, the copra processing method has to be improved in order to increase copra quality and eliminate toxins in Philippine copra and copra meal. The Wijose process demonstrates an on-farm utilization of coconut fruit parts, the processing of which does not require the application of complex technologies. The process utilizes an improved copra processing method that simplifies the value chain of the product and a high recovery of every coconut part and waste residues.

The hot-air dryer produced high quality copra that is aflatoxin free. The MCDM gave the best fit to the experimental drying data that could adequately describe the drying characteristic of thin-sliced coconut meat. Physical and combustion characteristics of the torrefied dried coconut leaves were superior and were comparable to coal, making it more suitable for fuel applications.

The conceptual design of the Wijose process for coconut processing for the production of VCO and dietary flour was developed in a coconut farm plantation in Lutucan I, Sariaya, Quezon Philippines.

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She received her M.S. and Ph.D. degrees in Chemical Engineering at the University of the Philippines-Diliman, Quezon City in 1993 and 2014 respectively. Her dissertation is about the improvement of the coconut processing that will develop new techniques and technologies in small coconut farms in the Philippines under the supervision of her adviser and co-author of this paper, Dr. Wilfredo I. Jose.

Dr. Pestaño looks forward to advance her study under some form of collaboration with the coconut industry stakeholders.