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PRODUCTS AND PROCESS INVOLVING COCONUT: PRACTICAL EXAMPLES FOR A COURSE IN MASS AND ENERGY BALANCE CALCULATIONS

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ABSTRACT

Calculations involving mass and energy balances are normally taken up in the first course in chemical engineering. However, its significance as a basic skill in many aspects of the chemical engineering domain is usually underrated. Environmental concerns, sustainability, and resource conservation are currently being incorporated in design and engineering work. Example problems that illustrate such principles should be included in the first course in chemical engineering. Of all the plants grown for commercial exploitation, the coconut has the most number of uses. Known as the tree of life, the coconut can also be a symbol of sustainability. It provides food, shelter, energy, and other diverse uses. The products and processes involving coconut are so numerous and diverse, that a book about these processes will amply illustrate the elementary principles in mass and energy balance calculations for beginning chemical engineering students. Processes involving coconut can thus demonstrate the principles in mass balance without chemical reactions, mass balance with chemical reactions, heat and energy balance. This paper presents the basis of selecting coconut products and processes as practical examples for a first course in mass and energy balance calculations. Example problems related to coconut processes are included.

Key Words: *Coconut, products, processes, mass and energy balance, calculations*

1. INTRODUCTION

Mass and energy balance calculations usually influence a student's interest in the chemical engineering field because it is different from the usual calculations encountered in his/her chemistry subjects. Aside from illustrating the basic chemical engineering principles, topics for the sample problems (both solved problems and problems to be solved for practice) should also be a medium for imparting extra knowledge and other learning objectives. Injecting concepts of sustainability, resource conservation, and environmental protection in the problems add realistic situations that can stimulate the student's interest. Using examples that leave positive impact on the students should be part of a teacher's arsenal.

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The major topic in the first course in chemical engineering is mass and energy balance calculations (MEBC). Implicitly, problems are solved using techniques in algebra and,arithmetic (or only algebra in some cases). All chemical engineering students are expected to have already taken up arithmetic and algebra subjects in high school and first year in college. They have solved word problems that deal with mixing, compounding, separation, etc. without knowing that those problems are actually elementary mass balance problems. The strategy is to view or regard problems in MEBC under steady-state situations as word problems in algebra or arithmetic.

The textbook used in MEBC has a profound effect on students. It can be arranged so that the presentation starts with the simplest idea, and principles and relationships are given in a graduated manner so that the students are not overloaded. Problems involving coconut fit into this strategy. The processes for coconut are numerous, and vary from simple mixing and separation to complicated large scale processes. Transforming a raw part of the palm or the fruit to a certain product employs many unit operations and unit chemical conversions. A book for the first course in chemical engineering can be written to apply the elementary mass and energy balances on processes involving coconuts. The applications and uses of the coconut plant and fruit are so diverse that numerous types of problems can be crafted. Moreover, many principles in engineering can be illustrated through these practical examples.

2. THE COCONUT AND ITS USES

The research started with a review of the gasification process, and familiarization of the GEGS used at the Mechanical Engineering Laboratory of the University of the Philippines Department of Mechanical Engineering. The gas cleaning method was studied, and modifications were made to further enhance the quality of the producer gas. The research activities required 200 man-days to complete. It consisted of modifications of the existing gasifier, including the design of its oil bath filter, the addition of the gas demister and the newly designed oil bath filter, and the coupling of the gasifier separately to two diesel engines with their respective generators; operation and test runs with the modifications; actual operation and data gathering; and evaluation of the data gathered.

The coconut palm (*Cocos nucifera*) is under the family *Arecaceae* (palm family), and is the only species in the genus *Cocos*. It is a large, exposed palm reaching an average height of around 25 meters. The trunk has typical diameters of about 30 to 50 centimeters, thickened at its base and is usually smudged with annular scars. Its leaves which are crowded at the apex of the trunk, 3.5 to 6 meters long with a stout petiole, are capable of producing an inflorescence which will develop into a cluster of coconuts.

The coconut tree, which has grown in tropical Asia and the Malayan islands since prehistoric times, is one of the most useful and widely distributed of all the tropical trees. It can live under warm and humid conditions, but it can withstand short periods of temperatures below 21°C (70°F). In addition, it has the ability to adapt to soils of heavier texture, although it has natural preference to sandy, well-aerated and well-drained soils.

The coconut palm is a very versatile tree, in which every part of it has a significant economic value:

Meat. Referred to as "white solid endosperm", the meat is the part of the coconut that is most used for food. Coco flour, dessicated coconut, coconut milk, coconut chips, candies, *bukayo* or local sweetened shredded coconut meat, *latik,* copra, and animal feeds are some of the products which can be obtained from coconut meat.

Oil. Coconut oil is the most readily digested of all the fats of general use in the world. In addition, it has high saponification value in view of the molecular weight of most of the fatty acid glycerides contained therein. Products from coconut oil are soap, lard, coco chemicals, crude oil, pomade, shampoo, and cooking oil.

Leaves. Coconut leaves produce good quality paper pulp, midrib brooms, hats and mats, fruit trays, waste baskets, fans, beautiful midrib decors, lamp shades, place mats, bags, and utility roof materials.

Water. Also known as "liquid endosperm", it is used to produce coconut water vinegar, coconut wine, nata, and as substitute for dextrose.

Husk. Coconut husks are made of bristle fiber (10%), mattress fiber (20%), and coir dust and wastes (70%). Coir fiber can be used as substitute for jute in making rice, copra, sugar, coffee, bags and sandbags; and in making pulp and paper (kraft). Coco gas, lye insulator, *insoflex*, and plastic materials can be obtained out of coir dust (PCARRD, 1988), (BPI, 2010).

Popularly known as the "tree of life", "king of the tropical flora", "man's useful tree", and many others, this palm tree has given mankind myriad uses and benefits from its roots to the tips of its branches (Labadan, 2006). Hence, utilizing the numerous processes involving coconut best illustrate the typical mass and energy balance problems, which can be included in the first course in chemical engineering.

3. COURSE ON MASS AND ENERGY BALANCE CALCULATIONS USING PROBLEMS ON COCONUT PROCESSES

In developing the course for elementary mass and energy balance calculations, the student should be introduced with the different unit operations and unit processes. Then, lectures on coconut can be done to familiarize them with its numerous uses and benefits. At this point, the student can qualitatively pinpoint or enumerate the unit operations involved in producing a particular product from coconut. For example, the production of coconut chips mainly involves shredding (size reduction) and drying (simultaneous heat and mass transfer). When they are already familiar with the unit operations and its applications to coconut processes, the quantitative part of the course can now be employed together with other necessary chemical engineering principles. The topics are arranged in the following manner, based from the textbook on mass and energy balances by one of the authors (Jose, 2011):

Chapter 1: Introduction
Chapter 2: Mathematical, chemical, and physical principles
Chapter 3: Mass balances without chemical reaction
Chapter 4: Mass balances with chemical reactions
Chapter 5: Heat balance
Chapter 6: Graphical solution
Chapter 7: Equilibrium
Chapter 8: Energy balances

4. EXAMPLES OF CONSTRUCTED PROBLEMS

In discussing problems involving coconut processes, the instructor should emphasize that the coconut is an important renewable resource that contributes to environmental equilibrium. For example in problems involving combustion, the products may emit carbon dioxide but the coconut plant takes it back through photosynthesis.

The following are some of the constructed problems that can be included in the book for a course in mass and energy balances:

Simple Problems

1. Coconut husks normally contain an average of 50% lignin, 30% cellulose, and 20% hemicellulose. How many grams of each component does 20 kilograms of the husks contain?
2. The composition of the medium for *nata de coco* (microbial cellulose) production is 54 liters of water, 4 kg of sugar, 2 kg of grated fresh coconut, 1.2 liters of glacial acetic acid, and 12 liters of mother liquor. The total volume is 72 liters. How much of each component is needed to produce a 20-liter solution?

The above problems can be given to students at the beginning of the course without any chemical engineering background yet. They can solve the problem because they know how to solve problems in algebra and arithmetic.

Mass Balance Problems with Unit Operations

1. 4,000 kg/h copra containing 55% oil (mass) is to be extracted with 16,000 kg/h of n-hexane solvent. The solvent contains 98% n-hexane and 2% oil. The underflow contains 2.5 kg solution/kg inert materials. This solution consists of 0.2 mass fraction of oil with the rest being n-hexane. What is the percentage recovery of the oil from the copra?
2. Activated carbon from coconut is used to recover acetone from an air-acetone mixture. The air-acetone mixture contains 15% acetone and flows into the absorber at 180,000 liters/min at 80°C and 100 kPa. The rate of flow of the activated carbon is at 160 kg/min. The amount of acetone is reduced to 2% by volume. What is the flow rate of the outgoing activated carbon with the adsorbed acetone? What is the volumetric flow rate of the outgoing gas at STP?

The above problems involve single unit operation, namely extraction and adsorption, that is easy to solve. It shows a range of problems concerning coconut processes and products.

Mass Balance Problem with Recycling Operation

1. 100 kg/h of coconut water containing 1.5% solids is processed in a freeze concentration system to a final concentration of 15% solids. The raw solution enters a chiller and then to a crystallizer where ice crystals form. The product concentrate is withdrawn. 0.05 kg solution adheres to every kilogram of crystals. The ice crystals are sent to a tank where 5 kg of the ice crystals melts. The adhering solution and the melted ice are recycled back to the chiller. How many kg of the 15% concentrate is obtained? How much ice is obtained from the melter (tank)? What is the concentration of the recycled solution (% solids)?

Mass Balance Problem with Chemical Reactions

1. Coco gas (gas obtained from the pyrolysis of coconut coir dust) can be transformed to form synthesis gas for the manufacture of methanol. A typical synthesis gas analysis is 32.98% CO, 65.96% H_2, 0.34% CH_4 and 0.72% air. The synthesis gas is sent to a converter where 7% of the reactants is transformed to methanol according to the following reaction:.

$$CO + 2H_2 \rightarrow CH_3OH$$

The gases from the converter are sent to a condenser and separator where the whole amount of liquid methanol is removed. The gases containing CO, H_2 and inert materials are recycled and mixed with the fresh feed. To avoid accumulation of the components not involved in the reaction, a portion of the recycle gas is purged. What should be the purge to recycle ratio to keep the components not involved in the reaction (air and CH_4) at 9.4%? What is the composition of the purge gas? What is the % yield of CH_3OH? The mole ratio of H_2 to CO is kept at 2 at all points in the system.

Other Sample Problem

1. The following reactions are possible during the pyrolysis of biomass such as coconut coir dust in the total absence of oxygen:
   a. $C + H_2O \rightarrow CO + H_2$
   b. $C + 2H_2O \rightarrow CO_2 + 2H_2$
   c. $C + 2H_2 \rightarrow CH_4$
   d. $C + CO_2 \rightarrow 2CO$
   e. $CO + H_2O \rightarrow CO_2 + H_2$
   f. $2CO + 2H_2 \rightarrow CH_4 + CO_2$

   Calculate the heat of reaction of each at 25°C and 1 atm from data on heat of formation.

5. EXAMPLE OF SOLVED PROBLEM

The following solved problem involves elementary mass balance without reaction to a single unit operation equipment.

The meat of a 9-month old maturing coconut can be processed to a dried crispy food product. The sweetened maturing coconut product is usually dried with an initial moisture content of 40% (dry basis) down to a final moisture content of 3% (dry basis). Air enters the drier at 90°C, 1 atm, and essentially dry; it leaves at 50°C, 100 kPa, and contains 0.35 kmol water/kmol dry air. For every 100 kg product/min,

a) How much water is evaporated?
b) How much is the mass of the feed?
c) What is the volumetric flow rate of the outgoing air in m^3/min?

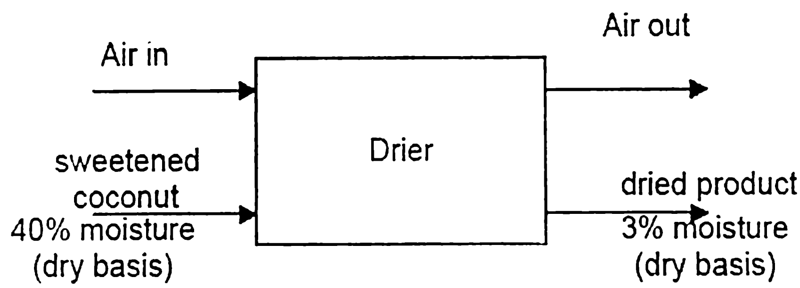

Figure 1. Block diagram for the sample problem

A basis of 1 minute operation can be used to solve the given problem. By applying the arithmetic method, ratio method, and the use of indirect ideal gas law, the amount of water evaporated, the original mass of the feed, and the volumetric flow rate of the outgoing air can be calculated.

$$\text{water evaporated} = 100\text{ kg product} \times \frac{100}{(3+100)}\frac{\text{kg BDS}}{\text{kg product}} \times \left(\frac{40}{100} - \frac{3}{100}\right)\frac{\text{kg H}_2\text{O evap.}}{\text{kg BDS}} = 35.92\text{ kg}$$

$$\text{mass of feed} = 100\text{ kg product} \times \frac{100}{(3+100)}\frac{\text{kg BDS}}{\text{kg product}} \times \frac{(100+40)}{100}\frac{\text{kg feed}}{\text{kg BDS}} = 135.92\text{ kg}$$

$$\text{vol. flow rate of air out} = 35.92\text{ kg H}_2\text{O evap} \times \frac{\text{kmol H}_2\text{O}}{18\text{ kg H}_2\text{O}} \times \frac{1}{(0.35)\frac{\text{kmol H}_2\text{O picked up}}{\text{kmol BD air}}}$$

$$\times \frac{(1+0.35)}{1}\frac{\text{kmol wet air}}{\text{kmol BD air}} \times \frac{22.4\text{ m}^3}{\text{kmol}} \times \frac{50+273}{0+273} \times \frac{101.325}{100} = 206.7\frac{\text{m}^3}{\text{min}}$$

6. APPLICATION TO NEW PRODUCTS/PROCESSES

One of the new and the most popular products derived from coconut is Virgin Coconut Oil (VCO). It is currently promoted as healthy oil, comparable or even better than olive oil. The oil is processed at low temperature to prevent the loss of vitamins and other essential components. Several methods of production are available, which can illustrate some principles in mass balance.

The figures below are sample process and block flow diagrams for virgin coconut oil production, which can be used to test the student's ability to perform mass and energy balance calculations.

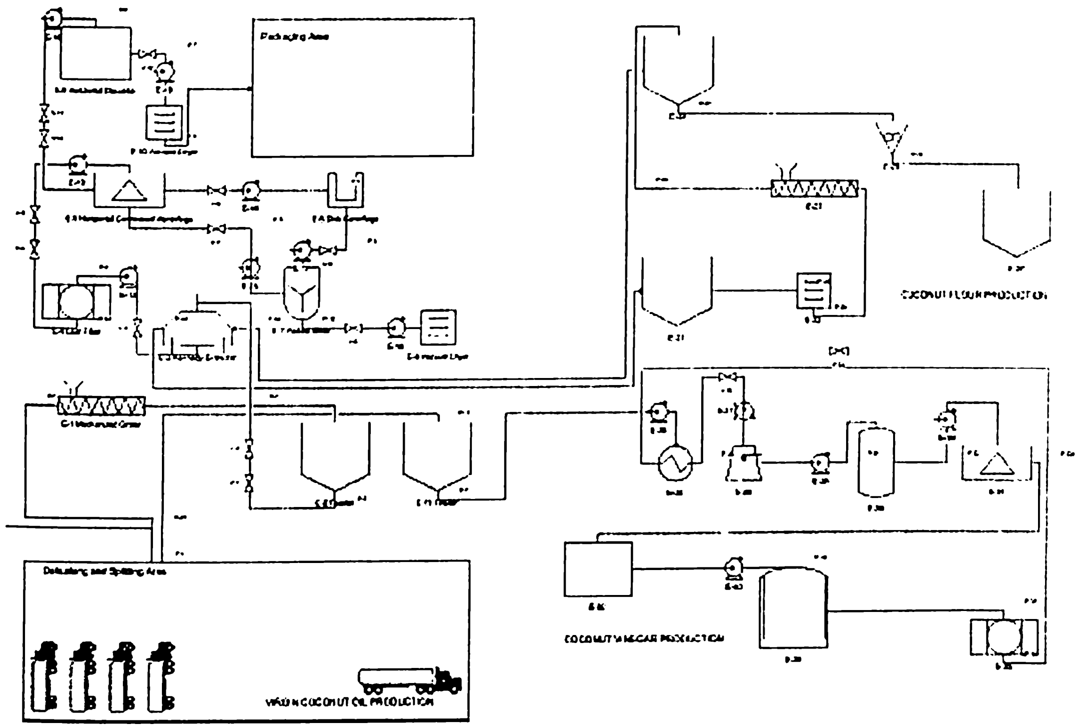

Figure 2. Process flow diagram for production of different products from coconut

The block flow diagram in Figure 3 shows the modified wet process for VCO production. Manual dehusking is the first step, which separates the husk from the nut. Then, manual splitting is done by opening or slicing around the equator of the nut producing two half sections. Coconut water is collected, which can be used for coconut vinegar production. Coconut meat obtained from the nut is then grated through a mechanical grater to reduce its size and for ease of extraction. Milk extraction follows through the use of a Kennedy extractor upon adding water to the grated coconut meat. The wet meal will be filtered using a leaf filter. The filtrate from the wet meal will undergo centrifugation to produce skim milk and coconut cream. Skim milk is centrifuged (using a disk centrifuge) to separate whey and wet protein. The wet protein is mixed with that from a three-way solid bowl centrifuge before drying the substance to produce dried protein. The acquired coconut cream is made to pass through a decanter where it is continuously settled and coalesced, producing crude virgin coconut oil. The process is stopped once the oil has separated from the cream. The crude virgin coconut oil is then processed further to obtain better purity of the product. The filtered oil is further dried under vacuum without heating. This process will remove moisture in the oil that cannot be evaporated in the heating step, thereby further lowering the moisture content of the coconut oil. After vacuum drying, the product is now ready to be packed and shipped to various locations.

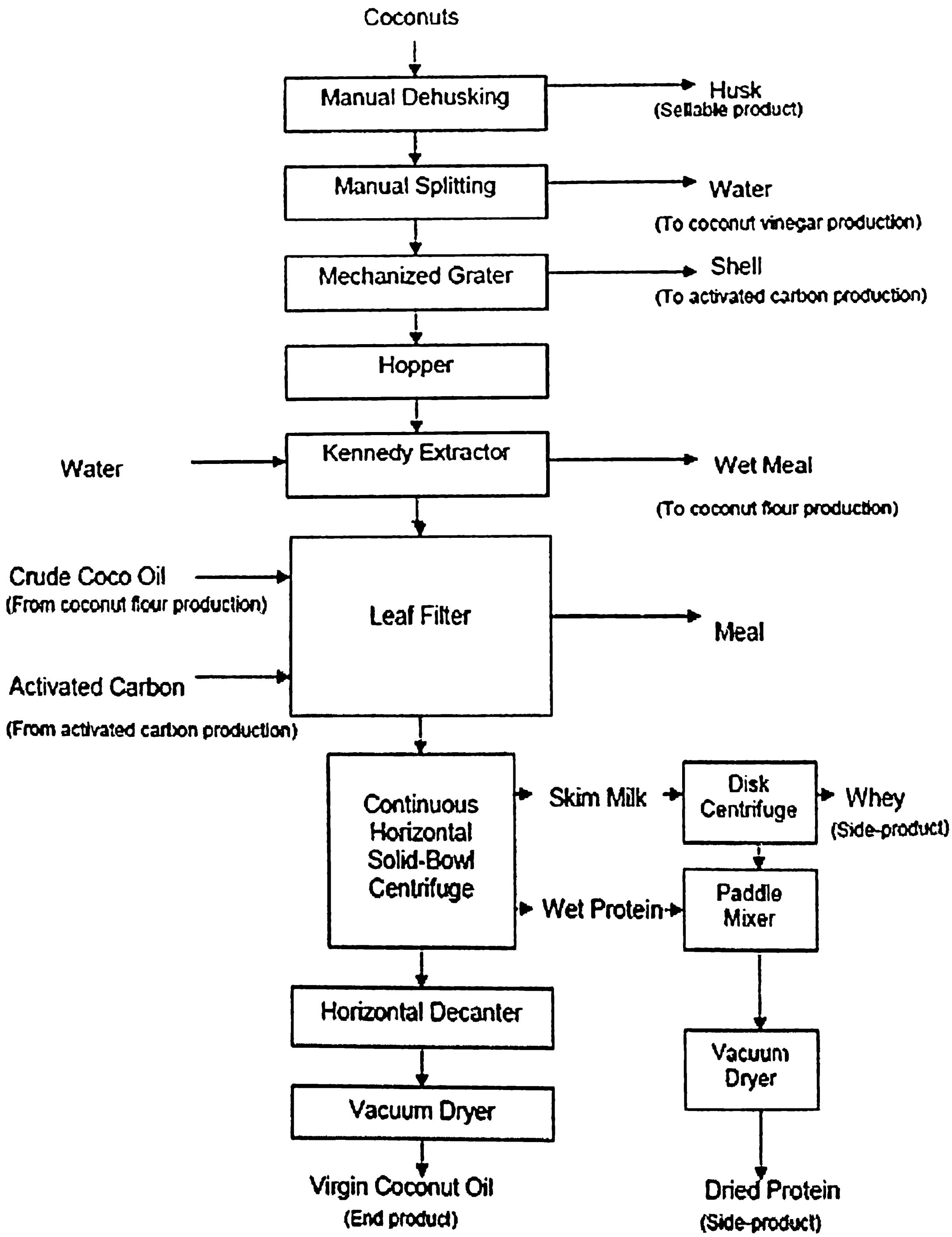

Figure 3. Modified wet process for Virgin Coconut Oil (VCO) production

Through this process, one liter of VCO is produced from 15 to 20 nuts with a weight of 700 to 850 grams per dehusked nut. The student should be able to perform overall and individual mass and energy balances for all equipment as illustrated in Figure 3, and account all missing information from the given data on the modified wet process for VCO production.

7. CONCLUSION

The use of coconut processes as examples to elementary mass and energy balance calculations is very practical since they illustrate most of the unit operations being studied by starting chemical engineering students. In addition, the students are being exposed to a wide variety of the uses of coconut, thus increasing their environmental awareness. It is possible to write a book on elementary mass and energy balance using coconut products and processes as examples, which can be used as an instructional material for the first course in chemical engineering.

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