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Process simulation of integrated palm oil mill, refinery and oleochemical processes

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Abstract. Processes involved in the palm oil industry can be categorized into three main operations; upstream operation (planting and milling), midstream operation (physical/chemical refining), and downstream operation (palm-based oleochemical processing). For the last few years, some industrial key players have emphasized a change from stand-alone operations towards an integrated manufacturing facility. This has become the basis idea for integration of palm-based production processes. It includes material integration, shared energy and utility resources and waste-to-feed utilization. Integrated process however, involves a complex network; thus, the process has to be simulated to analyze its feasibility in terms of process throughput and material, energy and utility consumption. Hence, this paper addresses the basis to simulate the integrated palm oil process using process simulator Aspen Plus V8.6 for its dynamic capabilities in adjusting process variables to meet the required capacity for a target product. This study is critical in providing a basis and overview of the typical processes in palm oil industry and the possible interrelations associated with the proposed integrated facility for palm oil-based production.

1. Introduction

For the past few years, there has been emphasis on a transformation from stand-alone operations towards integrated manufacturing facility. The integrated manufacturing facility is intended to produce a more complete range of value-added products from the raw fruits/seeds to consumers' usage [1].

In current practice, upstream operation involves planting, harvesting and processing of fresh fruit bunch (FFB) to obtain the crude palm oil (CPO). As for the midstream operation, it involves further refining of CPO to obtain refined, bleached and deodorized palm oil (RBDPO), and to separate the RBDPO into palm stearin and palm olein. Lastly, the downstream operation deals with oleochemical processing such as fractionation (separation) of palm fatty acids distillate (PFAD) from the refining section. Many plantation companies in Malaysia manage both upstream and midstream operations, but they are mostly operated separately.

Recently, the East Coast Economic Region of Malaysia (ECER) in 2010 has promoted the investment for Palm Oil Industrial Cluster (POIC) to be constructed at Gebeng Industrial area in Pahang [2]. The POIC is planned to facilitate the upstream (plantation, milling and milled products) and downstream (food-based, oleo and biodiesel) of the palm oil industries.

This recent revelation shows the possibility of integrating the palm oil-based processes for sustainable production of palm oil upstream and downstream products. However, the literature review conducted has found no evidence of integrated palm oil process that addresses the possibility of integrating the processes in production of palm oil and palm-derived products. Therefore, via process simulation, the process throughput, operating variables, and material, energy and utility consumption can be analyzed for both stand-alone process unit and integrated process unit.

2. Research approach

Processes involved in palm oil industry can be categorized into three main section; milling, refining (physical/chemical) and oleochemical processing. To carry out this analysis, the involved processes are briefly described in the following section.

2.1. Process description

2.1.1. Oil Extraction (Milling Process). Milling process involves oil extraction from the palm FFB. The raw fruits are fed into a sterilizer and then sent to a threshing drum where the fruits are separated from the bunches. The fruits then sent to digesters followed by pressing in a screw presser. The pressed oil is pumped to the clarification tank for oil separation. The separated oil containing fibrous solids is further separated in high speed centrifuge and then sent to vacuum dryer [3]. The desired products from the milling process are crude palm oil (CPO) and kernel nuts; while the waste consists of palm oil mill effluent (POME), empty fruit bunch (EFB) and fruit fiber.

2.1.2. Oil Refining (Degumming, Bleaching and Deodorizing Process). There are three stages in CPO refinery: degumming, bleaching and deodorizing of oil. In degumming, the CPO feed is treated with phosphoric acid (H_3PO_4) with a concentration of 85% and demineralized hot water [4]. In bleaching, the degummed oil is treated with bleaching earth in a vacuum bleaching mixer before entering the vacuum bleacher. In deodorization, the degummed and bleached oil is treated at high temperature of between 240°C to 260°C, under vacuum condition (2-4 mmHg) with direct steam injection of 2.5-4.0 % of oil weight. The products from oil refining process are refined, bleached and deodorized palm oil (RBDPO) and palm fatty acid distillate (PFAD), while the waste consists of spent bleaching earth (SBE).

2.1.3. Oleochemical Processing (*Palm Oil Fatty Acid Fractionation*). Oleochemical process involves various production of specialty products. Fractionation of palm fatty acid distillate (PFAD) from the oil refining process is considered in this analysis. The operation consists of four main process units: drying column, pre-cut column, C16/18 column and fatty acid evaporator. Drying column is used to distill out the water content from PFAD feed. The first fractionation column (pre-cut column) is used to drawn off a C12-C14 fatty acids as by-product. The second fractionation column (C16/18 column) is producing a C16-C18+ fatty acids as final product.

2.2. Process Integration Approach

The aim of process integration is to integrate the use of materials and energy and to minimize the generation of emissions and wastes. Hence, the proposed integrated process is depicted in figure 1, where the whole manufacturing process of upstream, midstream and downstream processes in palm oil industry, are considered as a big picture of an integrated system with interconnecting processing units inclusive of process, utility and waste streams. There are two levels of integration in the proposed scheme. Firstly, the interconnection of material stream from one process unit to the other. Another integration level is the interconnection of centralized utility system (CUS) with each process plant unit, where the supply of utilities (water, electricity, steam and vacuum) to the process plant unit is centralized.

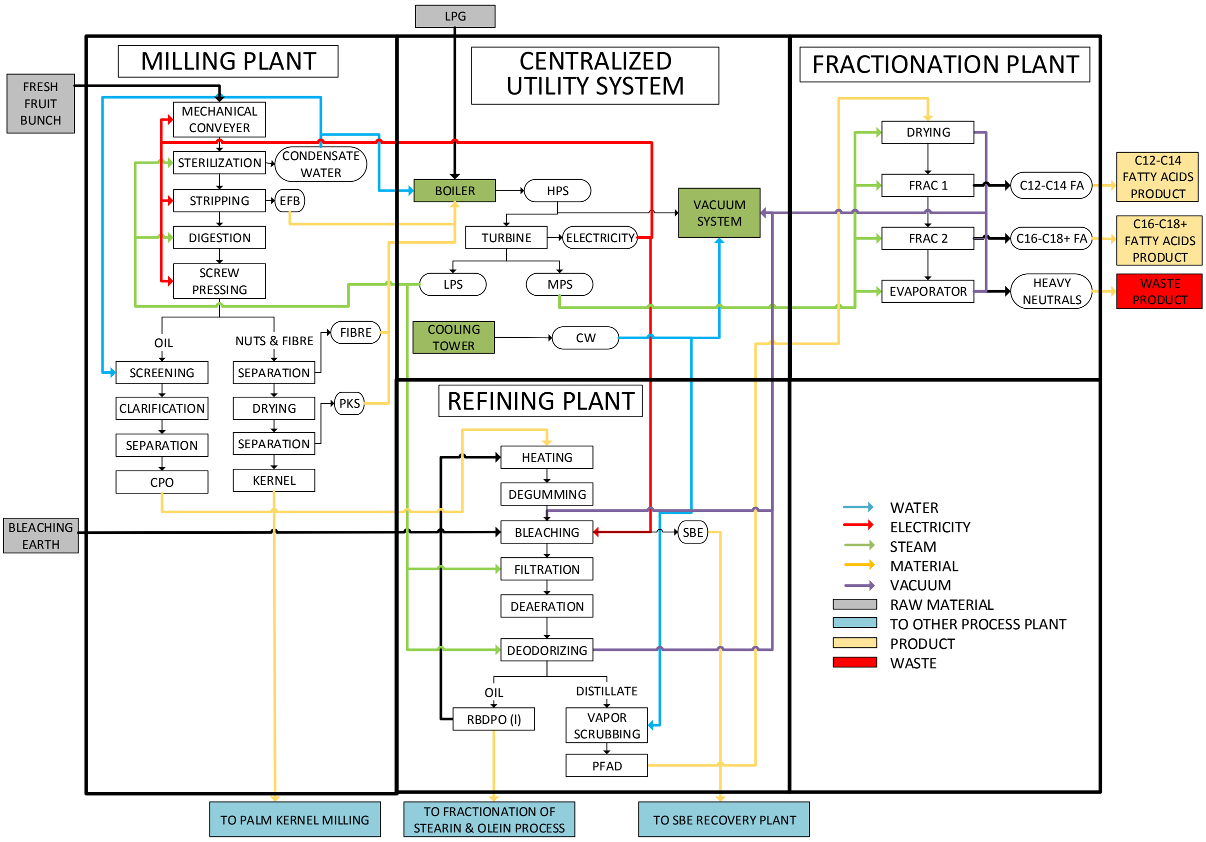

Figure 1. Proposed integrated process of milling, refining and fractionation process.

2.3. Simulation Procedure

The simulation of production process for upstream, midstream and downstream operations in palm oil industry is performed using the process simulator Aspen Plus V8.6. The main process data of the simulation are presented in table 1. For upstream process, the process units involved in milling are mostly the mechanical equipment that handle the solids (FFB). Solid model is employed for milling process simulation where the physical properties and chemical composition of the solid feed are obtained from [5] and [6] respectively. Data on chemical composition of the liquid feed (mesocarp oil of the FFB) is obtained from [7] and [8]. Feed to midstream and downstream operation comes from the subsequent product, starting from milling section, where its product (CPO) is the feed to the refinery section and product from refinery (PFAD) is then fed to the fractionation section.

3. Results and discussion

In this study, the integration is based on consideration of the whole manufacturing process of the analysis; milling, refining and fractionation of palm fatty acid distillate (PFAD). From a big picture, these three operations have the possibility for interconnection of the process units, utility and waste streams. Through preliminary analysis of mass balance data for each operation, they share similar requirement on utilities (electricity, steam, cooling water and hot water). Abundance waste stream from milling operation such as EFB, mesocarp fibers, palm kernel shell (PKS) and condensate water from sterilizer which is part of the mixture effluent from milling process (POME)) is a potential feed for generating utilities. These wastes can be used to fuel up the boiler to generate steam. The steam generated can be used for both steam supply to the process and for turbine operation to generate electricity, which are among the utilities required to operate all the three processes.

Table 1. Main process data for process simulation of palm oil processes integration.

Features		Value	Features		Value
Milling			***Fractionation***		
Feed composition			Dryer		
	Solid fraction	35.11% cellulose, 25.26% hemicellulose, 28.01% lignin, 5.68% extractive, 5.93% ash		Temperature/ Pressure	~ 30 mbar / ~ 128°C
				No. stages	3 stages
	Liquid fraction	0.2% C12, 1.1% C14, 44.1% C16, 4.5% C18, 39.2% C18:1, 10.5% C18:2, 0.4% C20:0	Column 1		
				Temperature/ Pressure	~ 140°C / ~ 7 mbar (top), ~ 230°C (bottom)
				No. of stages	20 stages
	Feed flowrate	45,000 kg/hr		Product	C12 - C14
	Steam	LPS; 10080 kg/hr			
	Product	CPO	Column 2		
Refining				Temperature/ Pressure	~ 140°C/ ~ 6 mbar (top column), ~ 230°C (bottom)
Feed		CPO from milling			
Temperature & Pressure		90-110°C / Vacuum (8 mbar)			
BE flowrate		2% of feed		No. of stages	20 stages
H_2PO_4		85% conc., 0.2% of feed		Product	C16 – C18 +

Table 2. Composition of the main process stream calculated by simulation.

		FFB	CPO	RBDPO	PFAD	C12-C14	C16-C18+
T (°C)		***30***	***201.5825***	***353.3637***	***130***	***166.2392***	***153.0815***
P (bar)		***1***	***0.1973847***	***0.9973684***	***0.9973684***	***0.024673***	***0.011843***
Mass Flow (kg/hr)		***45000***	***10274.58***	***6972.9***	***3309.084***	***50.00038***	***2000***
CELLULOS	Cellulose	27.00%	-	-	-	-	-
XYLAN	Hemicellulose	19.42%	-	-	-	-	-
LIGNIN	Lignin	21.55%	-	-	-	-	-
EXTRACT	Extractives	4.37%	-	-	-	-	-
ASH	Ash	4.56%	-	-	-	-	-
H2O	Water	0.00%	0.08%	0.00%	0.34%	0.02%	0.01%
Lauric	C12:0	0.05%	0.19%	0.10%	0.38%	0.00%	0.00%
Myristic	C14:0	0.25%	1.07%	0.80%	1.65%	0.11%	0.00%
Palmitic	C16:0	10.19%	43.94%	41.82%	48.14%	73.79%	33.00%
Stearic	C18:0	1.04%	4.52%	5.20%	3.07%	1.34%	2.88%
Oleic	C18:1	9.06%	39.30%	41.00%	35.48%	17.96%	49.15%
Linoleic	C18:2	2.43%	10.51%	10.49%	10.48%	6.66%	14.96%
Heavy neutrals	C20:0	0.09%	0.39%	0.36%	0.47%	0.12%	0.00%
H3PO4	Phosphoric Acid	-	-	0.24%	-	-	-

Table 3. Energy and utility consumption calculated by simulation.

	Milling	Refining	Fractionation
Energy (kJ/hr)	8.00E+06	9.10E+06	1.86E+06
Vacuum duty (kJ/hr)	-5.28E+05	-2.42E+06	-5.13E+05
Steam (kg/hr)	10080	308.46	-
Hot water (kg/hr)	4937.63	-	-
Cooling Water (kg/hr)	-	2154.24	-

Based on table 2, it is found that the weight percent (wt%) of desired products from each process (milling, refining and fractionation) after the integration, is as according to current production of their stand-alone operation. However, the feed basis of the process integration performed is based on a stand-alone milling operation, where the capacity of a normal operational milling plant is 45 t/hr of FFB (based on observation and data collection from site visits). Therefore, the end-operation (fractionation process) is only able to produce a very small amount as compared to its current plant capacity of ~500kg/hr of C12-C14 fatty acids (current simulated production is only 50 kg/hr) and ~14,5000kg/hr of C16-C18+ fatty acids (current simulated production is only 2000 kg/hr). For instance, if the throughput is set from backwards, to accommodate a larger fractionation process capacity, the feed of PFAD required from refinery and CPO from milling sections will be larger. A larger capacity of milling for example, will generate a larger amount of waste that can be used to produce more amount of steam and more electricity generation for the operational consumptions. These changes can be simulated in Aspen Plus to obtain the value of energy and utility consumption (table 3) as compared to the waste generated and its conversion to energy in terms of steam and electricity generation capacity.

4. Conclusion

Process integration is an important branch of process engineering that refers to the application of system-oriented, thermodynamics-based and integrated approaches for the analysis, synthesis and retrofit of a process plant. Since the goals of process integration are to integrate the use of materials and energy and to minimize the generation of emissions and wastes, hence integration of upstream, midstream and downstream operations in palm oil-based industry is relevant to minimize the resources by direct transfer of material from one process unit to another and sharing of energy supplies from a centralized utility system as previously depicted in figure 1. Hence, by using the process simulation tools, a basis and overview of the typical processes in palm oil industry and the possible interrelations within the proposed integrated facility can be observed and analysed virtually for further details and retrofit of process design to realize a performance target. For future work, a comprehensive integration of palm oil processes based on current capacity of downstream operation can be done to analyse its effect to the throughput of raw material required at the upstream operation and the impact to overall integrated process, in terms of waste generation, raw material and energy and utility consumption.

Acknowledgment

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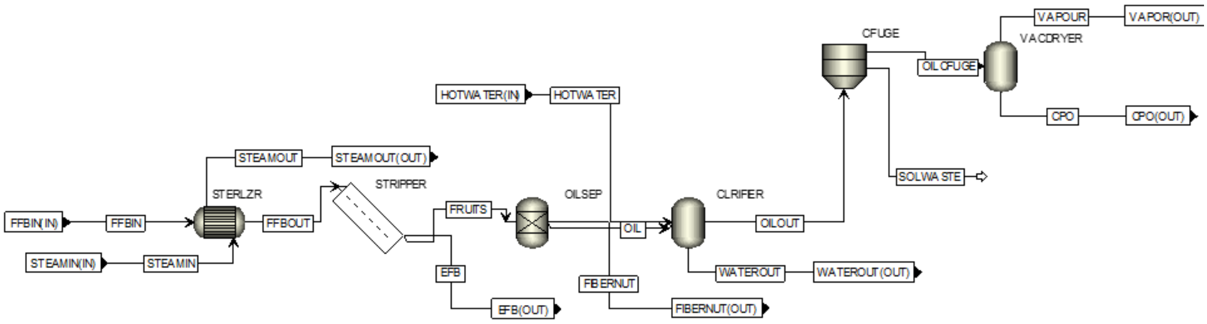
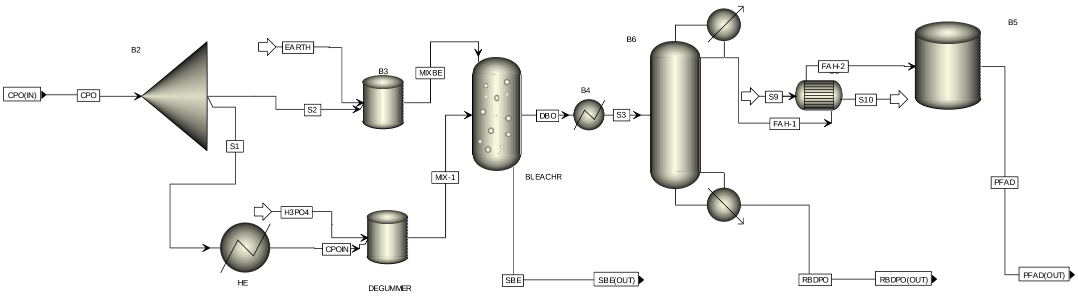
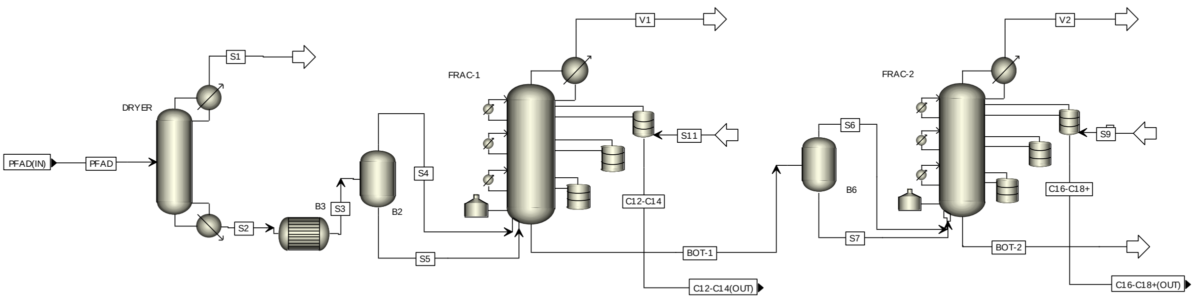
Appendices



Appendix A. Upstream process simulation (milling process flow diagram).



Appendix B. Midstream process simulation (refinery process flow diagram).



Appendix C. Downstream process simulation (fractionation process flow diagram).