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Aspen Plus Simulation Analysis on Palm Oil Mill Effluent (POME) Recycling System into Bioethanol

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ABSTRACT

Indonesia is one of the largest exporting countries for palm oil production globally. In 2018, the country had a plantation area of 14.3 Million Ha, with palm Oil Production (Crude Palm Oil) of 40.5 million tons. It generates large amounts of waste, such as Palm Oil Mill Effluent (POME), empty fluid bunch (EFB), fiber, and shells. POME has an organic content and contains carbohydrates, lipids, and proteins. Generally, the POME by-products from palm oil mills in North Sumatra Province are processed using an Anaerobic treatment before environmental release. This method still disposes of pond waste. It produces CH_4 and bad smells in the environment. This research uses Aspen Plus software to analyze converting the POME into bioethanol renewable energy that reduces environmental pollution caused by POME. Bioethanol production is processed biologically by fermentation. Based on the analysis of simulation, 10 L tons/day POME can produce main products 0.187 L Ton/day bioethanol with the content of up to 41.95% C_2H_5OH, 9.29% H_2O, and 48.76% CO_2, and by-products of 9.823 L Ton/day with the content of 99.7% H_2O.

1. Introduction

Indonesia is one of the world's largest palm oil-producing and exporting countries. In 2018, the palm oil plantations area was 14.3 million Ha, producing about 40.5 million tons [1]. It is an essential sector for the developing economy of Indonesia. On the harmonized system (HS) palm oil group, in 2021, the largest export will be Other Palm Oil (HS 15119000), amounting to 85.35 percent of Indonesia's total palm oil exports. The most significant contribution to palm oil exports is Crude Palm Oil (HS 15111000), Other Palm Oil Kernel (HS 15132900), and Crude Oil of Palm Kernel (HS 15132110), with respective contributions of 9.40 percent, 5.05 percent, and 0.20 percent of total exports [2].

In 2018, the plantation of palm oil in Indonesia at Sumatera Island value production of 22.76 million tons from 8.38 million Ha, Java Island production of palm oil of 0.076 million tons from 0.037

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million Ha, Kalimantan Island gets the value production palm oil of 13.55 million tons from 4.88 million Ha, Sulawesi island get value production palm oil of 1.24 million ton from 0.53 million Ha, and Maluku and Papua get value production palm oil 0.33 million ton from 0.22 million Ha [1].

Crude palm oil (CPO) is processed from fresh fruit bunches (FFB) which are transported from plantations using trucks to palm oil mill (POM). The FFB is processed immediately in sterilizers for about 60 – 90 minutes and steamed up to 3 bars with a temperature between 120 ℃ – 130 ℃. The FFB from the sterilizer will be sent to the separation part to separate the fruits from the empty bunch. Fruits spikelets are conveyed into the digester to loosen the mesocarp from the nuts, which will pass into screw presses. Mesocarp from screw presses will be sent for clarification and purification to produce CPO. Nuts are cleaned to remove fiber from kernels, whereas the kernels will be processed for separation and Kernel drying, which results in palm kernel oil (PKO) [3-5], as shown in Figure 1.

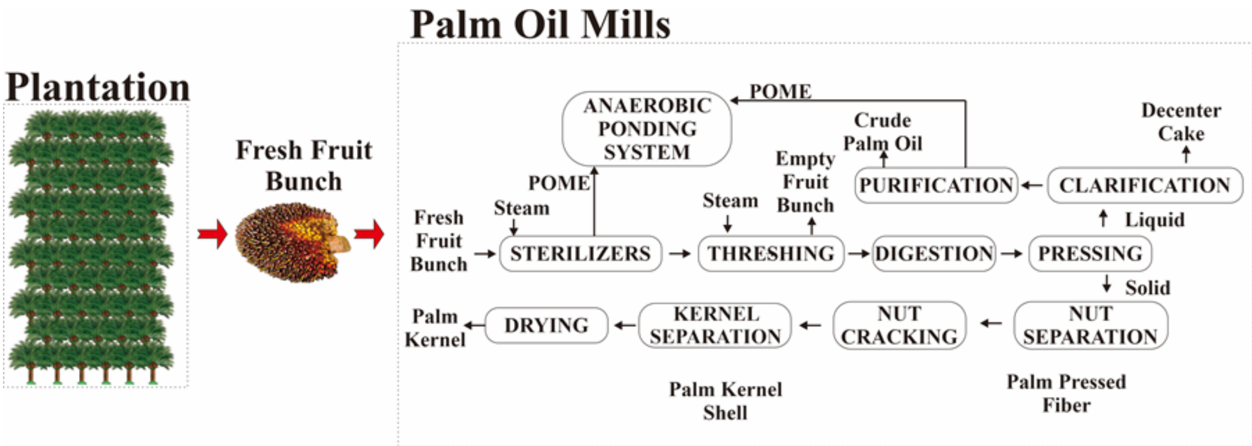

Fig. 1. Palm oil mill processes

Operating palm oil in the POM gives rise to waste as by-products, which can pollute the environment. The wastes generated from the FFB extraction process are palm oil mill effluent (POME), which contributes the most significant portion [6]. Waste generated contains POME 60% - 80% of FFB, empty fruit bunches (EFB) 22% - 23% of FFB, fiber 12% - 13.5% of FFB, shells 5% of FFB, decenter cake 3% of FFB and potash ash 0.5% of FFB [5-8]. In general, they are not utilized and discarded into the environment. Palm oil mills in North Sumatra Province are processing POME using an anaerobic ponding system before releasing it into the environment. There are three sources of wastewater such as hydro cyclone wastewater (approximately 4%), sterilizing condensate (approximately 36%), and separator sludge (approximately 60%) [7].

Indonesia has made regulations regarding quality standards for liquid waste from the palm oil industry, with maximum levels and pollution as follows: BOD 250 mg/L and 1.5 kg/ton, COD 500 mg/L and 3 kg/ton, TSS 300 mg/L and 1.8 kg/ton, oil and grease 30 mg/L and 0.18 kg/ton, Ammonia Total (NH_3-N) 20 mg/L and 0.12 kg/ton, then pH 6-9 and waste discharge maximum 6 m^3 ton raw material [9].

The composition and characteristics of POME depend on the quality of palm fruit, processing techniques, quality control of individual mills, harvest season, and others. General composition and parameters contained in POME, such as temperature: 80-90 °C, pH: 3.4-5.5, BOD: 10,000-44,000 mg/L, COD: 15,000-100,000 mg/L, TS: 11,500-79,000 mg/L, SS: 5,000-54,000 mg/L, TVS: 9,000 – 72,000 mg/L, TN: 80-1,400 mg/L, NH_3-N: 4-80 mg/L, oil and grease: 4,000-8,000 mg/L, P: 180 mg/L, K: 2,270 mg/L, Mg: 615 mg/L, Ca: 439 mg/L, B: 7.6 mg/L, Fe:46.5 mg/L, Mn: 2 mg/L, Cu: 0.89 mg/L, Zn: 2.3 mg/L [6, 10, 11], containing 0.5– 2% oil, 2–4% suspended solids, 93–96% water, 4–5% total solid and brownish colloidal suspension [10-13]. It is a non-toxic waste with high organic content and contains carbohydrates, lipids, and proteins [14]. The testing results, 1-liter POME samples were taken from local Palm Oil Mills in the Galang sub-district, Deli Serdang district, North Sumatra province, Indonesia, containing water of 921.7 % and carbohydrate of 1.75 %.

Sustainable bioenergy from palm oil in Indonesia indicates a higher environmental aspect. If the sustainability status of the social aspect and sustainability status of the economic aspect, Indonesia indicated that status was deficient. The bioenergy sustainability of palm oil in Indonesia is still low [15]. Palm oil mill waste is a by-product of palm oil mills that has not been appropriately utilized and is still being dumped into the environment. POME processing uses an anaerobic pond system (FATPIT) or mixing with EFB for composting [3, 11], as seen in Figure 2.

Fig. 2. The POME in Ponding (FATPIT)

Treatment POME like that will generate methane gas, leading to the ozone layer's thinning. Around 12.36 Kg of methane gas with every tone of POME [16]. Its global warming potential (GWP) is the second most important anthropogenic greenhouse gas in the atmosphere next to carbon dioxide [17] and pollutes the environment, as shown in Figure 3. The consequence of POME on the environmental land becoming barren and causing a foul odor. Therefore, there is a need for a method to convert POME into bioethanol without damaging the environment. The analysis in this paper emphasizes the design process using aspen simulation so that the conversion of POME into environmentally friendly bioethanol can be carried out.

Fig. 3. POME pollution in the environment

POME could be treated by biological, physical, thermochemical, and integrated treatments [6, 10, 13]. Various research on POME treatment methods to efficiency the best technology can be seen in Table 1.

Table 1
Various research on POME

Treatment Method	Description	Using	Result	Ref
Biological Treatment	Use microbes to degrade the organics	Fermentation	Biohydrogen and methane	[18]
		Anaerobic sludge blanket	Biohydrogen	[19]
		Two-Stage Anaerobic System	Biohydrogen	[20, 21]
		Direct Bioconversion	Bioethanol	[22]
		Fermentation	Bioethanol	[23]
Physicochemical Treatment	Use of physical separation	Ultrafiltration membrane	Fertilizer and animal feeds	[24]
Thermochemical Treatment	Use of heat and chemicals	Gasification	Biochar	[25]
Integrated Treatment	Use of Integrated systems that combine two or more treatment methods	anaerobic and aerobic	Electricity generation and heating	[26]
		Biological treatment and membrane treatment	Boiler feedwater	[27]

2. Methodology

2.1 System Simulation

Simulations will be carried out with Aspen Plus to save costs and avoid failures in manufacturing digester systems. Aspen Plus, as the simulation package, has many databanks for some models like mixers, pressure changes, phase separators, splitters, distillation columns, reactors, and heat exchangers, and solves the thermodynamic problem that occurs in real-time industrial implementation [28]. Specification properties and components of POME that will be processed in the simulation are adjusted to the actual components. Component specifications are entered into the simulation Aspen Plus.

2.2 Data Input

The simulation in this study will be designed to convert POME into bioethanol. Bioethanol is produced by fermentation of biomass sources, varying from agriculture energy plants to organic wastes. It can be classified as second-generation biofuels, nonfood crop feedstocks, agricultural and forest residues, and industrial wastes [29]. Carbohydrates/glucose ($C_6H_{12}O_6$) in biomass are produced from photosynthesis, and carbohydrates can be converted to ethanol (C_2H_5OH) in the fermentation process, as shown in equations (1) and (2), respectively.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2 \quad (1)$$

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad (2)$$

Bioethanol mixed with gasoline to become vehicle fuel in the USA is known as E10 (10% ethanol, 90% gasoline), E15 (15% ethanol, 85% gasoline), and Flexfuels (85% ethanol, 15% gasoline) [30]. In comparison, in Brazil they use E25 (25% ethanol, 75% gasoline) to E100 (100% ethanol), and in Europe they use E5 (5% ethanol, 95% gasoline) and E85 (85% ethanol, 15% gasoline) [31]. Several studies have also explained that the calorific value (HHV or LHV) of bioethanol originating from the second generation has values ranging from 18,490 MJ/kg to 19,900 MJ/kg, showing that there is an immense opportunity to use bioethanol for combustion [32].

2.3 Simulation Design

This simulation planning would process 10 tons L/day of POME, with a temperature range from 80 – 90 °C. The specification properties and components input to the simulation is based on actual POME conditions obtained in the field. The simulation design flow is shown in Figure 4.

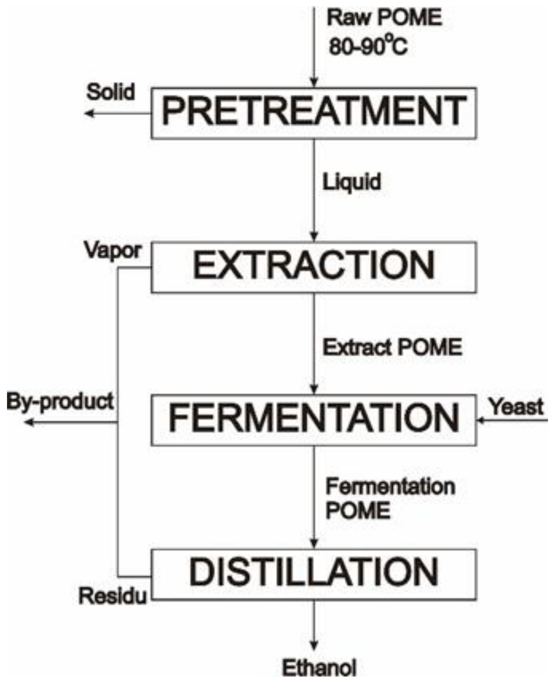

Fig. 4. Simulation Flow Design

Figure 4 shows the raw POME collected from the pond (FATPIT). The temperature in the pond is 80 – 90 ℃ separation occurs between solid and liquid (PRETREATMENT). Solid waste will be settled in the pond base, and liquid POME will be processed into bioethanol and reduced water levels by using the extract process for fermentation (EXTRACTION). Fermentation is a metabolic process that produces chemical changes in the glucose from the action enzyme (FERMENTATION). The products from fermentation processes occur in separating bioethanol with water content at boiling temperature (DISTILLATION). The Specification of POME then can be described on simulation by adopting Aspen Plus as the database. The component specifications implemented in the simulation are shown in Table 2.

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Table 2
The component specification from POME in the simulation

Component ID	Type	Component name	Alias
H_2O	Conventional	WATER	H_2O
$C_6H_{12}O_6$	Conventional	DEXTROSE	$C_6H_{12}O_6$
C_2H_5OH	Conventional	ETHANOL	C_2H_6O
CO_2	Conventional	CARBON-DIOXIDE	CO_2
N_2	Conventional	NITROGEN	N_2
NH_3	Conventional	AMMONIA	H_3N
P	Conventional	PHOSPHORUS-WHITE	P-W
K	Conventional	POTASSIUM	K
Mg	Conventional	MAGNESIUM	MG
Ca	Conventional	CALCIUM	CA
B	Conventional	BORON	B
Fe	Conventional	IRON	FE
Mn	Conventional	MANGANESE	MN
Cu	Conventional	COPPER	CU
Zn	Conventional	ZINC	ZN
BOD	Solid	-	-
C-O-D	Solid	-	-
TS	Solid	-	-
SS	Solid	-	-
TVS	Solid	-	-

The flow of the POME conversion processes into bioethanol is shown in Figure 5, with Aspen Plus simulation analysis developed based on the NRTL method.

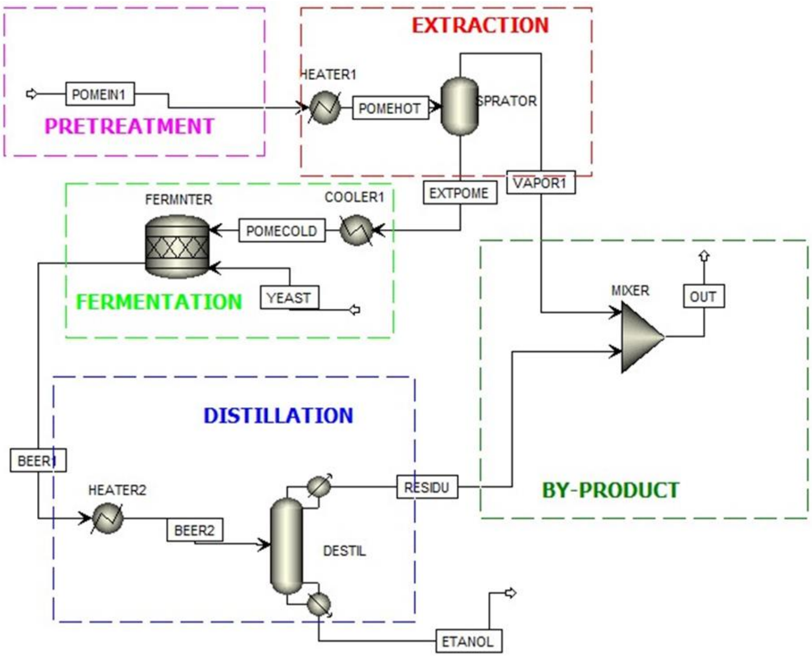

Fig. 5. Design primary simulation flowsheet

The processes in Figure 5 can be briefly explained as follows. The raw material in the form of POME (POMEIN1) undergoes extraction processes (HEATER1 and SPRATOR) flash2 palate models in Aspen Plus simulation) by a heating process at 100 °C and separating the POME into vapor and liquid. The water vapor formed will go to the storage area. At the same time, the remaining liquid POME will undergo a cooling process by a heat exchanger until 32 °C (COOLER1) before being accommodated in the fermentor unit (FERMENTATION) for fermentation processes. The fermentation process uses an RStoic pallet model (FERMNTER) by introducing yeast (YEAST) to grow nutritional microbes in POME, where the yeast medium can be assumed to be pure water in this simulation [31]. The fermented product (BEER1) will then be distilled in the DESTIL reactor to separate ethanol from water. In the distillation process, the fermentation product undergoes a heating process until it reaches a temperature of 110 °C on the heat exchanger (HEATER2). Ethanol with a boiling point of 78.5 °C will be separated and then go to the distillation unit, which is simulated using Column RadFrac (DESTIL). The configuration in DESTIL is that the distillate and reflux rates range from 0.2 kmol/hour and 2.3 kmol/hour, respectively. The distillation result that passes through the condenser will be the main product, namely bioethanol. At the same time, the by-products from VAPOR1 and RESIDUE will be removed from the system through a mixer unit (MIXER).

3. Results

The simulation results show that the product resulting from converting 10 L-ton/day of POME into bioethanol, the main product, is 0.186 L Ton/day, and the by-product is 9.823 L-ton/day. The specifications of the products referred to above can be seen in Table 3.

Table 3
Components of the main product and by-products based on simulation result

Description	Units	Main products	By-products
Total Mass Flow Rate	L-tons/day	0.186421435	9.823578565
H_2O	L-tons/day	0.017313318	9.797057394
$C_6H_{12}O_6$	L-tons/day	0	1.44513E-08
C_2H_5OH	L-tons/day	0.078208643	0.016995211
CO_2	L-tons/day	0.090897063	5.12735E-05
N_2	L-tons/day	3.32558E-07	0.002630477
NH_3	L-tons/day	2.07769E-06	0.000148254
P	L-tons/day	5.31019E-16	0.000338246
K	L-tons/day	8.25862E-36	0.004265662
MG	L-tons/day	6.35243E-57	0.001155675
CA	L-tons/day	6.92892E-76	0.000824945
B	L-tons/day	3.9842E-107	1.42815E-05
FE	L-tons/day	2.4377E-106	8.73803E-05
MN	L-tons/day	1.0485E-107	3.7583E-06
CU	L-tons/day	4.6657E-108	1.67244E-06
ZN	L-tons/day	3.69425E-54	4.32204E-06

Figure 6 shows a change in water content from 9.8 L Ton/day to 1.88 L, where a reduction of ± 82% water content occurred in the extraction process. The water content decreases in the distillation process to produce bioethanol of 0.017 L Ton/day.

Figure 7 shows that carbohydrates do not experience a change in mass during the initial treatment and extraction process. In contrast, the fermentation process has changed all the carbohydrate mass ($C_6H_{12}O_6$) into bioethanol (C_2H_5OH) and carbon dioxide (CO_2). It was also found that the mass of $C_6H_{12}O_6$ became zero, and there was an increase in C_2H_5OH and CO_2 after fermentation. However, the mass of C_2H_5OH decreases during the distillation process.

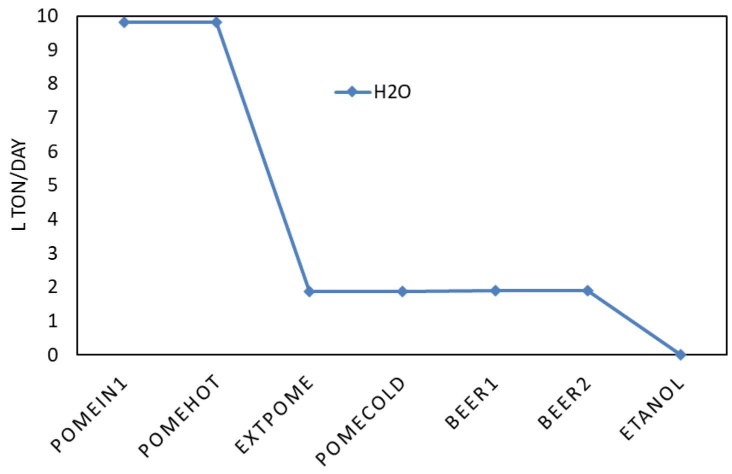

Fig. 6. Reducing water content in the bioethanol production process from POME

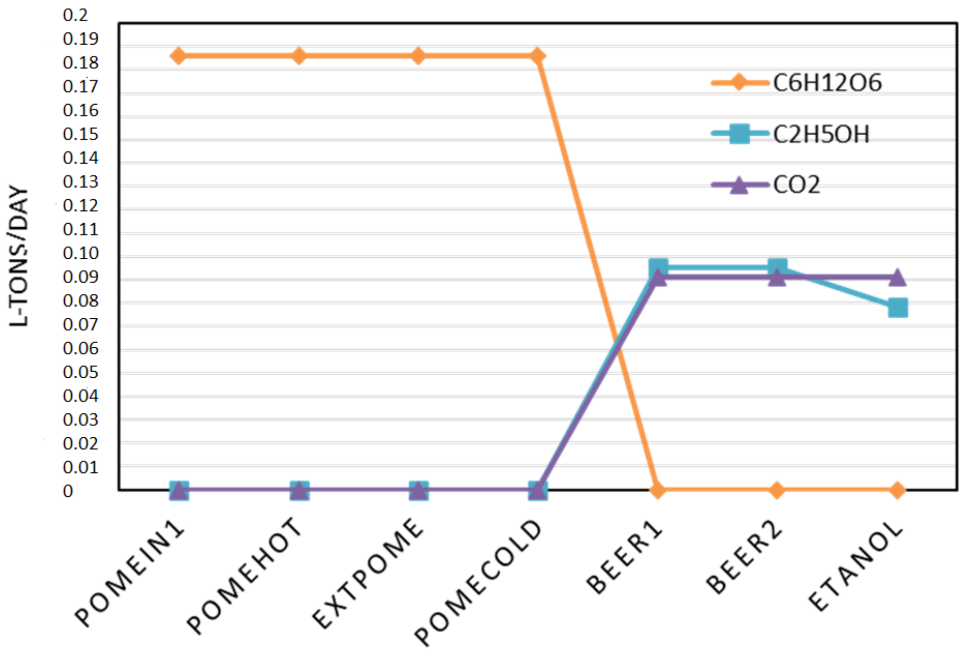

Fig. 7. Mass flow of carbohydrates, ethanol, and carbon dioxide

4. Conclusions

A simulation study found that 10 L tons/day of POME can be processed by fermentation to produce bioethanol with a content of 41.95% C_2H_5OH, 9.29% H_2O, and 48.76% CO_2, which has the potential to be increased and utilized as renewable energy. The by-product from this processing is 9,823 L tons/day with an H_2O content of 99.7%, which can be used as a source of fresh water in industry or plantations. This process is considered more environmentally friendly than the POM's anaerobic pond systems. As a continuation of the analysis, further research is underway to produce bioethanol from POME, which can be mixed with commercial internal combustion engine fuel.

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