Feasibility of Biodiesel Business and Oleo Chemical Industrialization

Hassan I. El Shimi, Hanem A. Sibak, Nahed K. Attia, and Shakinaz T. El Sheltawy

***Abstract*— Biodiesel "or Green-Oleum" as a renewable energy source, has recent interest worldwide because of energy crisis, excessive emissions and declining of fossil fuel, and the demands for oleochemicals market development. It produced by transesterification of oils and fats in presence of homogenous or heterogeneous catalysts. Scientists have challenges in optimizing the biodiesel processes. Feedstock is the bottleneck of green-oleum industry. Upgrading of feedstock oil will make revolution in the oleochemicals industry, especially when Brent crude oil spot rose in 2020 as expected. In the present research, a mass balance and feasibility study were achieved for production of one million ton biodiesel from different feedstocks such as used cooking oil (UCO), Jatropha *curcas* oil (JCO) and micro-algae oil (MAO) using sodium orthosilicate (Na_4SiO_4) as a catalyst based on the previously optimized conditions. The total production cost (TPC), profitability indictor (PI), pay-back period, return on investment (ROI) and break-even analysis were evaluated to investigate the sustainability of biodiesel business and oleochemicals marketing. Successful results were reported for green-oleum production from all feedstocks under certain restricted conditions.**

***Index Terms*— Biodiesel, Feasibility, Oleochemicals, Transesterification,**

I. Introduction

The mineral oil supply crisis and its deep psychological impact on public life is the trigger to search and develop for alternative energy resources [1-3]. Biodiesel "or green-oleum" is a renewable, non-toxic and biodegradable substitute fuel along petro-diesel to create blends [4]. Technically, biodiesel is produced by transesterification process of vegetable oils (edible or non-edible) with short-chain alcohols (e.g. methanol) in presence of homogeneous [5-7] or heterogeneous catalysts [8,9] with more than 97% yield [8]. Green-Oleum however requires much simpler manufacturing steps and operating conditions, and is therefore low in investment volume [1]. The development of green-oleum seems to be a sustainable way for producing a reliable fuel for Diesel engines and oleochemicals industry marketing [2].

Oleochemical is the sum of the transesterification and hydrolysis processes which convert the natural oils into sustainable products such as fatty acids, fatty alcohols, fatty acid methyl esters (or biodiesel), fatty amines and glycerin [8]. Its global market was evaluated to be approximately 24 million tons in 2016, and it expected to grow with rate of 7% in 2017 [8]. The Asia-Pacific (mainly Malaysia and Thailand) has about 70% of the market [5]. The predominant application for oleochemicals is for producing detergents and making soaps and personal care items, where 55% of market shares go for fatty alcohols, 30% for fatty acids and 15% for biodiesel, bio-lubricants, bioplastics and solvents [5]. Biodiesel has received much attention in recent years worldwide, so it represents the fastest growing sub-sector of oleo chemicals industry [3].

Biodiesel production is available now and growing throughout the world but still considered as a new business [4]. Feedstock is the controlling factor of biodiesel industry and therefore the oleochemicals production; as it represents more than 80% of production cost (PC) [8]. Moreover, food crisis versus diesel fuel debate will rose if edible virgin oils (e.g. palm, soybean, sunflower, etc.) were used for green chemicals production [1]. Thus, utilization of waste oils from cooking process, microalgae biomass and non-edible jatropha *curcas* oils are concerned for biodiesel industry development, as they will offer a triple facet solution: environmental, economic and waste control [6]. The initial point of Oleochemicals industries development is to find a sustainable feedstock, whatever recycling of waste oils or investigation of virgin non-edible oil. Also, the production technologies have to be modified and optimized in order to increase the economic potentials of the industry.

Optimization of biodiesel production processes using many feedstocks were excessively performed [8] as no further discussion will presented here. However, the feedstock must be sustainable; available, cheap, avoiding the confliction with food crisis and obtaining a qualified biofuel, so the process feasibility should be studied; to detect which one is feasible and sustainable for biodiesel business and oleochemicals industrialization based on the economic situation and the governmental policies of each country [1].

The objectives of this research are to conduct a mass balance and feasibility study for production of One million ton (1.0 MT) biodiesel from different feedstocks such as waste cooking oil (WCO), Jatropha *curcas* oil (JCO) and microalgae oil (MAO) using sodium orthosilicate (Na_4SiO_4) as a catalyst based on previously optimized conditions in order to mandate B10 by 2026 in Thailand.

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II. PROCESS DESIGN AND BACKGROUND

A. *Biodiesel Production Process*

The obtained oil (WCO, JCO, MAO) is filtered and heated to 65°C, and then reacts with the methyl alcohol (CH_3OH) in presence of powdered Na_4SiO_4 catalyst as shown in Fig 1. After reaction completion, the catalyst was removed through settlers to use in the next batch. The products mixture is distilled under vacuum to recover the excess methanol, and then transferred into a decanter to get two distinct layers of biodiesel and glycerol due to the densities difference of 0.86 and 1.22 g/ml, respectively. The glycerol is stored as it obtained in high purity (min. 98%), while the FAMEs are treated with hot water (55°C) for 2 times to get rid of residual alcohol, catalyst and glycerol traces. The water layer is then decanted to purify the biodiesel before storing.

B. *Background of Case Study*

The diesel fuel prices are stable in Thailand as its spot was recorded US$1.35 per gallon in 2000, and US$ 1.87 in December 2016. There is a policy in Thailand since 2011 to blend at least 3% green-diesel with petro-diesel (B3), and B7 is currently applied and mandate. The Thai Government encourages the marketing of biodiesel business by raise the people awareness, offering tax incentives and subsidies (e.g. project land and water). Currently, the daily registered capacity of biodiesel is 5 ML obtained from 11 factories up to 2016, and B10 is optional according to the statistics report of Department of Energy Business, Ministry of Energy, Thailand, 2016. Thailand mandated B5 since Jan 2012 and B7 since Jan 2014. Blending percentage can be adjusted in accordance with palm oil supply abundance. The targeting biodiesel consumption is 5 ML/D in 2026 in order to mandate B10 where the diesel-base demand is 51 ML/D. To access this objective, different feedstocks should be explored for biodiesel production and therefore, oleochemicals marketing. This research includes a mass balance and feasibility study for annual production of 1.0 MT biodiesel using different stocks such as WCO, JCO and MAO via Na_4SiO_4 catalysis. A biodiesel factory with annual production capacity of 1.0 MT will achieve approximately 66% of the targeting biodiesel consumption in 2026 based on the biodiesel roadmap constructed by the Thai Biodiesel Production Association (TBPA).

III. RESULTS AND DISCUSSION

A. *Process Results*

Investigation of heterogeneous catalyst like sodium orthosilicate (Na_4SiO_4) in biofuel production could overcome the barriers of homogeneous materials such as KOH and H_2SO_4 since the products are obtained in high purity (min. 98%), and therefore the manufacturing cost is minimized, so the profitability indicators (PI) will raise by at least 10% [10]. Sodium silicate is available worldwide especially in Egypt by many manufacturers like *Silica Egypt Co.* and *the Egyptian Saudi Co. for Modern Chemicals*. The domestic consumption of palm oil in Thailand in 2016 is approximately 1.0 MT, in which 50% can be recyclable. The transesterification reaction conditions are kept in optimum levels to produce 1.0 MT of biodiesel per year; catalyst loading is 5.87% (wt/wt oil), Methanol-to-WCO molar ratio is 6, reaction time is 3h, catalyst recyclability is 5 times at 65°C and 350 rpm obtaining 97% fatty acid methyl esters "biodiesel" [8].

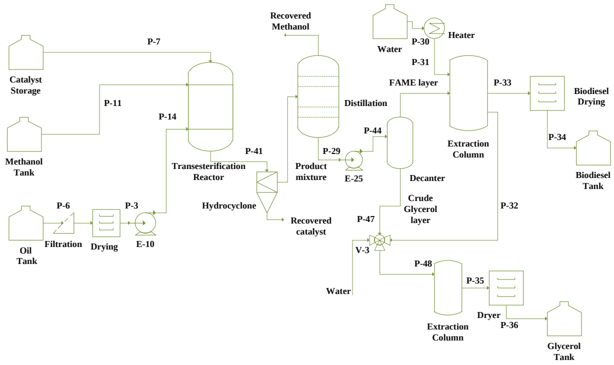

Fig. 1. Flow diagram for biodiesel production using Na_4SiO_4 catalyst.

B. *Feasibility Study*

Several assumptions were selected to evaluate the production of 1.0MT biodiesel where raw materials cost and products selling prices are used in accordance with the international scope. The recent feasibility study accounts the international marketing price of US$600 per metric ton for JCO and MAO including all preprocesses costs. Also, the process catalyst will be recovered and marketed with US$50 per ton less than its purchased cost according to contracting with the manufacturer. The free fatty acid (FFA) content of the stock oil is an important issue for methyl esters synthesis [11]. To utilize feedstocks like JCO or MAO for biodiesel production using Na_4SiO_4 as a catalyst, the FFA shouldn't exceed 3% [12]. The FFA in the feedstock may be successfully lowered to 1% via oil esterification with 60% w/w of methyl alcohol-to-oil ratio and 1% w/w of concentrated sulfuric acid-to-oil ratio at 60°C for 3h [9,11]. Esterification of feedstock is necessitate to avoid formation of gel-like materials, and therefore the quality and conversion yield of products are markedly enriched [9]. The storage capacity of oil, biodiesel and glycerol is suggested to be only one week and 35% of the alcohol amount was detected as a recovery [8]. The materials flow cost accounting sheet is presented in Table 1. The total equipment cost (TEC) is estimated for each individual stockfeed and listed in Table 2 [13]

The design of each piece of equipment was performed and approximated from the daily continuous biodiesel production capacity in accordance with the feeding, reaction and discharging time intervals, and then the units number and unit cost (US$) of each specific equipment used in the processing were determined as detected in Table 2. It is assumed that the working days of biodiesel plant are 300 per year for 3 shifts per day.

The capital investment (CI) for 1.0MT biodiesel processing using WCO, JCO and MAO stocks are calculated as listed in Table 2. The capital investment (CI) is the sum of fixed capital investment (FCI) and working capital investment (WCI), and FCI is the sum of physical plant cost (PPC) and indirect plant cost (IPC). WCI is assumed to be 15% of FCI because all products are kindly marketed. All costs were detected with respect to the TEC. Biodiesel production cost

(BPC) was estimated as listed in Table 3. Electricity cost is assumed to be US$0.1 per kilowatt hour (kWh), and its consumption is assumed to be 70kWh per ton of biodiesel [5]. The labor cost is assumed to be US$ 10000 per employee per year for the Thais case study however it is varied according to the economic situation of the country.

The feedstock is the controlling factor of biodiesel and oleochemicals industries [12]. In general, the raw material and electricity contribute around 75% of total costs [13]. In the present case, the feedstock represents about 44.1% of BPC for WCO, 53.5% for JCO and 53.3% for MAO.

For investment evaluation and decision maker, some economic indicators (EI) must be estimated such as the net profit (NP, US$/year), return on investment (ROI, %) and pay-back time (year) according to "(1)" to "(3)". For a new investment, the minimum ROI in an established market is 20%, and the maximum pay-back time is 5 years [14,15]. Gross earnings of 10% were nevertheless allocated for taxes expenses.

As reported in Table 3, the ROI was calculated to be 215%, 35% and 33% for biodiesel production from WCO, JCO and MAO, respectively, with minimum net profit of US$36 million per year inferring that biodiesel industrialization using various feedstocks rather than palm kernel oil in Thailand seems to be feasible.

$$\text{Net Profit (NP, US\$/year)} = \text{Total Revenues} - \text{BPC} \quad (1)$$

$$\text{ROI\%} = \frac{\text{NP}}{\text{CI}} \text{x100} \quad (2)$$

$$\text{Payback period (years)} = \frac{\text{FCI}}{\text{NP} + \text{Depreciation}} \quad (3)$$

IV. CONCLUSION

Mandating of B10 in Thailand by 2026 can be performed using WCO and MAO as feedstocks besides JCO biodiesel and oleo chemical production. A biodiesel factory with annual production capacity of 1.0 MT will achieve approximately 66% of the targeting biodiesel consumption in 2026 based on the biodiesel roadmap constructed by the Thai Biodiesel Production Association (TBPA). Industrialization of algal biodiesel seems to be currently more realistic than Jatropha biodiesel because the later has many risks related to the climate change and the environmental concerns in Thailand.

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TABLE 1: MATERIALS FLOW COST ACCOUNTING SHEET

Item	Unit cost (US$/t)	Quantity (t/yr)	Total Cost (US$/yr)		
			WCO	JCO	MAO
Process Inputs					
Crude Oilstock	*	1030927.8	412371134	618556701	618556701
Methanol	500	**	417323189	422515275	426401513
H_2SO_4 (esterification)	1000	10309.3	10309278	10309278	10309278
Catalyst (Na_4SiO_4)	250	60515.5	15128866	15128866	15128866
		Raw materials	***855132467***	***1066510120***	***1070396358***
Process Outputs					
Methyl esters "Biodiesel"	1000	1000000	1000000000	1000000000	1000000000
Glycerol (98% purity)	400	100000	40000000	40000000	40000000
Recycled catalyst (97%)	200	58700	11740000	11740000	11740000
Recovered alcohol	500	***	146063116	147880346	149240530
		Revenues	***1197803116***	***1199620346***	***1200980529***
	WCO	JCO	MAO		
* Unit cost (US$/t)	400	600	600		
** Methanol quantity (t/yr)					
Esterification	618556.7	618556.7	618556.7		
Transesterification	216089.7	226473.8	234246.3		
*** Total alcohol amount required*	834646.4	845030.5	852803.0		
*** Recovered methanol (35%)	292126	295761	298481		

TABLE 2: TOTAL EQUIPMENT COST (TEC) AND CAPITAL INVESTMENT (CI)

Equipment	Units No.	Unit cost (US$)	Total cost (US$)	Capital Investment Category	% of TEC	Cost US$
Oil storage tanks (200 m^3)	120	50000	6000000	*Physical Plant Cost (PPC)*		
Methanol storage tanks (200 m^3)	97	50000	4850000	Total equipment cost (TEC)	100	29117000
H2SO4 storage tanks (100 m^3)	3	25000	75000	Equipment delivery cost	10	2911700
Grinders (Ball or vertical roll mills, 10ton/hr capacity, 46kW)	2	300000	600000	Installation cost	20	5823400
Splitters/Mixers (Propeller, 10 hp)	40	10200	408000	Piping	20	5823400
Esterification reactors (Jacketed & Agitated 50 m^3)	20	113000	2260000	Buildings	10	2911700
Transesterification reactors (Jacketed & Agitated 50 m^3)	15	113000	1695000	Utilities (Electrical distribution, instrument air and steam generation systems)	15	4367550
Filters (Hydrocyclone, 1m diameter, 25-50 m^3/h)	6	50000	300000	Instrumentation & Control	15	4367550
Decanters/Centrifuges (bottom driven 3m diameter)	6	37000	222000	Site Development	10	2911700
Pumps (progressive cavity type, 30gallon/min)	60	11000	660000	Auxiliary buildings	5	1455850
Extraction columns/Distillation Towers (3m Diameter,15m Height)	6	500000	3000000		**PPC**	**59689850**
Biodiesel storage tanks (200 m^3)	116	50000	5800000			
Glycerol storage tanks (200 m^3)	12	50000	600000	*Indirect Plant Cost (IPC)*		
					% of PPC	
		TEC	26470000	Design and Eng.	20	11937970
		110% TEC	29117000	Contractor' fee	20	11937970
				Contingency	10	5968985
				Legal expenses	10	5968985
					IPC	**35813910**
			Fixed Capital Investment (FCI) = PPC+IPC			95503760
			Working Capital Investment (WCI): 15% FCI			14325564
			Capital Investment (CI) = FCI+WCI			**109829324**

TABLE 3: BIODIESEL PRODUCTION COST (BPC) AND PROFITABILITY INDICATORS

Category	**Unit cost (US$)**	**Cost (US$)**		
		WCO	JCO	MAO
Direct Production Cost (DPC)				
Raw Materials		855132468	1066510121	1070396358
Miscellaneous materials	10% M&O	573023	5730226	5730226
Electricity	US$0.1/kWh & 100kWh/ton biodiesel	10000000	10000000	10000000
Shipping & Packaging	1% TEC	291170	291170	291170
Maintenance and operational cost (M&O)	6% Fixed capital investment (FCI)	5730226	5730226	5730226
Operating labor	US$10000/employee/year	5000000	5000000	5000000
Depreciation	Straight-line depreciation over 15 years factory life	1747020	1747020	1747020
Plant overheads	50% of labor and M &O	5365113	5365113	5365113
Interest	2% TEC	582340	582340	582340
Property insurance cost	5% TEC	1455850	1455850	1455850
Rent	2%TEC	582340	582340	582340
		886459549	***1097837202***	***1101723439***
Indirect Production Cost (IPC)				
Research and Development	5% of DPC	44322977	54891860.08	55086172
General expenses	25% of operating labor and M&O	2682556	2682556	2682556
Packaging & storage	10% of operating labor and M&O costs	10730226	10730226	10730226
		48078556	***58647439***	***58841751***
Biodiesel Production Cost (BPC) = DPC + IPC		***934538105***	***1156484641***	***1160565190***
	Gross earnings, US$/year	***263265011***	***43135706***	***40415339***
	Net Profit (NP), US$/year	***236938510***	***38822135***	***36373805***
	Return on Investment (ROI), %	***215***	***35***	***33***
	Pay-back time, year	***0.4***	***2.3***	***2.5***