Optimization of Biodiesel Production from Crude Palm Oil via Two-Step Catalyzed Process

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ABTRACT:

The objective of this work is to investigate the optimum conditions in biodiesel production from crude palm oil (CPO) by using two-step catalyzed process. The response surface methodology (RSM) with 5-level and 3-factor central composite design (CCD) is used to optimize the three reaction variables such as methanol to oil molar ratio, catalyst concentration and reaction time. Due to the CPO has high free fatty acid (FFA) content that it is not suitable to produce biodiesel. As a result to achieve good conversion to methyl ester, the FFA of CPO must reduce to less than 2 %wt by esterification in the first step after that transesterification is in the second step. The result showed the optimum condition derive via RSM were 2.2:1 of methanol to oil molar ratio, 0.5 %wt sulfuric acid catalyst, 60 min reaction time and temperature 60 ^{0}C in esterification reaction. The optimum conditions in transesterification reaction were using 7:1 of methanol to oil molar ratio, 1.2 %wt potassium hydroxide, reaction time 70 min and temperature 60 ^{0}C. The percentage of methyl ester in the obtained product was 96.57 %wt.

INTRODUCTION:

Biodiesel is increased attention as an alternative, non-toxic, biodegradable, and renewable diesel fuel. Biodiesel is usually produced by the transesterification of vegetable oil or animal fat with short chain alcohol such as methanol or ethanol. Biodiesel has higher oxygen content than petroleum diesel and its use in diesel engines have shown great reductions in emission of particulate matter, carbonmonoxide, sulfur, polyaromatics, hydrocarbons, smoke and noise. In addition, burning of vegetable-oil based fuel does not contribute to net atmospheric CO_2 levels because such fuel is made from agricultural materials which are produced via photosynthetic carbon fixation (Zullaikuh, 2005). Therefore in this work is a two-step catalyzed process is used for the production of biodiesel from CPO. Sulfuric acid is selected as an acid catalyst at the first step to reduce the amount of FFA. As for the second step, potassium hydroxide is then used to catalyst the transesterication reaction in which triglyceride reacted with methanol. The optimized through response surface methodology (RSM) is applied for both steps. Special attention is paid to optimize the first step being the acid catalyzed and process variables such as methanol to oil molar ratio, H_2SO_4 concentration and reaction time. In the second step being the alkali catalyzed process and process variables such as methanol to oil molar ratio, KOH concentration and reaction time.

METHOD:

First step; esterification reaction.

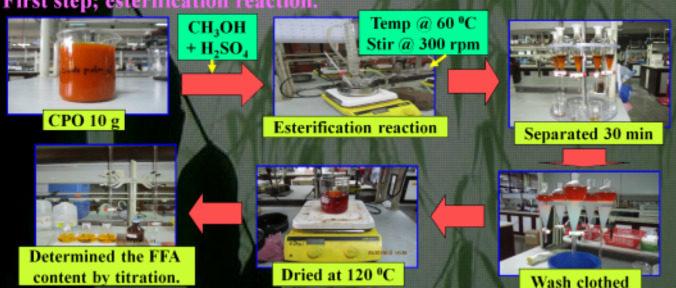

Figure 1. Esterification reaction process.

Second step; transesterification reaction.

Transesterification reaction is performed as though the esterification process. But, it was using the calculated amounts of potassium hydroxide and methanol were then mixed to esterifield oil 10 g in three necked flask. At the end of the reaction, the purified methyl ester was analyzed amount of fatty acid methyl ester (FAME) by gas chromatography (GC).

Table 1. showing the variables and levels for central composition design (CCD)

Variables	Symbols	Esterification code levels[a]					Transesterification code levels[a]				
		-1.68 (-α)	-1	0	+1	+1.68 (+α)	-1.68 (-α)	-1	0	+1	+1.68 (+α)
Methanol to oil molar ratio %(wt/wt)	M	0.66	1	1.5	2	2.34	0.96	3	6	9	11.04
Catalyst concentration %(wt)	C	0.16	0.5	1	1.5	1.84	0.16	0.5	1	1.5	1.84
Reaction time (min)	T	39.6	60	90	120	140.4	39.60	60	90	120	140.40

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RESULT:

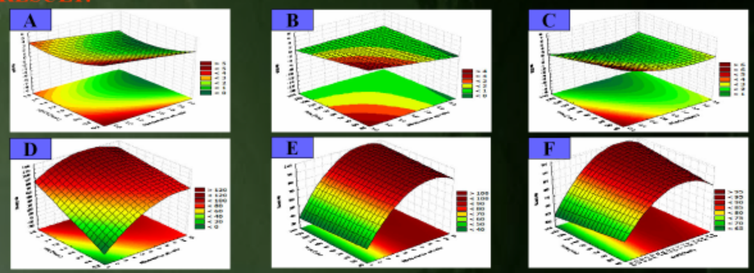

Figure 2. Surface plots showing the effect of; (A) methanol to oil molar ratio and H_2SO_4 concentration, (B) methanol to oil molar ratio and reaction time (min), (C) H_2SO_4 concentration and reaction time (min), (D) methanol to oil molar ratio and KOH concentration, (E) methanol to oil molar ratio and reaction time (min), (F) KOH concentration and reaction time (min).

The multiple correlations (R^2) in esterification step had value of 0.973 (limit 0.80). The predicted model for % FFA (Y) in term of code factor was shown in Equation 1.

$$Y = 17.406-(5.474\times M)-(7.264\times C)-(0.114\times T)-(0.052\times MM)+(2.187\times CC) +(2.481\times 10^5\times TT)+(0.055\times MC)+(0.043\times MT)+(0.019\times CT) \text{ ---Equation 1.}$$

Figure 3 (A), (B) and (C), the FFA content reduced to less than 2 %wt got to optimum condition 1.7:1-2.2:1 of methanol to CPO molar ratio, 0.3-1.8 %wt H_2SO_4 and 50-140 min reaction time. As for the % FAME in transesterification step with a coefficient of R^2 in value of 0.995. The predicted model for %FAME (Y) in terms of code factor was shown in Equation 2.

$$Y = -22.613+(20.698\times M)+(69.639\times C)-(0.149\times T)-(1.047\times MM)-(20.374\times CC) +(7.432\times 10^{-5}\times TT)-(3.701\times MC)-0.011\times MT)+(90.081\times CT) \text{ ---Equation 2.}$$

Figure 3 (D), (E) and (F), the FAME amount at more than 90 %wt got to the optimum condition 6:1-11:1 of methanol to esterifield oil molar ratio, 1.0-1.8 %wt KOH and 40-140 min reaction time.

Table 2. showing the fuel properties of biodiesel product in this work.

Properties	CPO biodiesel	Community biodiesel standard
1. Density at 15 ^{0}C (Kg/m^3)	860	860-900
2. Viscosity at 40 ^{0}C (CSt)	4.65	1.9-9.0
3. Flash point (^{0}C)	171	> 120
4. Water and sediment (% vol)	0.01	< 0.2
5. Acid value (mg KOH/g)	0.23	< 0.80
6. Fatty acid methyl ester (FAME, %wt)	96.57	96.50

CONCLUSIONS:

The optimum conditions for biodiesel production were determined with the aid of the central composite design (CCD). The optimum conditions in the first step were found to be as follows 2.2:1 of methanol to oil molar ratio, 0.5 %wt H_2SO_4 and 60 min of reaction time with temperature at 60 ^{0}C. These conditions can reduce FFA from 6.58 %wt to 1.54 %wt which is work complied in requirements to less than 2 %wt. The second step were 7:1 of methanol to oil molar ratio, 1.2 %wt KOH and 70 min reaction time with temperature at 60 ^{0}C. The percentage of fatty acid methyl ester content (FAME) from this optimized condition was 96.57 %.

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