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APPENDICES

APPENDIX A

EXPERIMENTAL AND ANALYSIS METHODS

A-1 Free Fatty Acids, AOCS Official Methods Ca 5a-40

Definition

This method determines the free fatty acids existing in the sample.

SCOPE

Applicable to all crude and refined vegetable oils, marine oils and animal fats

Apparatus

1. Oil sample bottles 115 or 230 ml (4 or 8 oz), or 250 ml Erlenmeyer flasks.

Reagents

1. Ethyl alcohol, 95%. The alcohol must give a definite, distinct and sharp end point with phenolphthalein and must be neutralized with alkali to a faint, but permanent pink color just before using.
2. Phenolphthalein indicator solution 1% in 95% alcohol.
3. Sodium hydroxide solution accurately standardized. Table 1 for the appropriate normality of the expected free fatty acid concentration range in the sample.

Table 1 Free fatty acid range, alcohol volume and strength of akali

FFA range (%)	Sample (g)	Alcohol (ml)	Strength of alkali
0.00 to 0.2	56.4 ± 0.2	50	0.1 N
0.2 to 1.0	28.2 ± 0.2	50	0.1 N
1.0 to 30.0	7.05 ± 0.05	75	0.25 N
30.0 to 50.0	7.05 ± 0.05	100	0.25 or 1.0 N
50.0 to 100	3.525 ± 0.001	100	1.0 N

"FFA, free fatty acid; N, normality"

Procedure

1. Samples must be well mixed and entirely liquid before weighing; however, do not heat the sample more than 10°C over the melting point.

2. Use Table 1 to determine the sample weight for various ranges of fatty acids. Weigh the designated sample size into an oil sample bottle or Erlenmeyer flask
3. Add the specified amount of hot neutralized alcohol and 2 ml of indicator.
4. Titrate with standard sodium hydroxide, shaking vigorously until the appearance of the first permanent pink color of the same intensity as that of the neutralized alcohol before, the addition of the sample. The color must persist for 30 seconds.

Calculations

1. The percentage of free fatty acids in most types of fats and oils is calculated as oleic acid, although in coconut and palm kernel oils it is frequently expressed as lauric acid and palm oil in terms of palmitic acid.

(a) Free fatty acids as oleic, % $= \frac{\text{ml of alkali} \times N \times 28.2}{\text{mass, g of sample}}$

(b) Free fatty acids as lauric, % $= \frac{\text{ml of alkali} \times N \times 20.0}{\text{mass, g of sample}}$

(c) Free fatty acids as palmitic,% $= \frac{\text{ml of alkali} \times N \times 25.6}{\text{mass, g of sample}}$

2. The free fatty acids are frequently expressed in terms of acid value instead of percentage free fatty acids. The acid value is defined as the number of milligrams of KOH necessary to neutralize 1 g of sample. To convert percentage free fatty acids (as oleic) to acid value, multiply the percentage free fatty acids by 1.99.

A-2 Acid Value, AOCS Official Method Cd 3D-63

Apparatus

1. Erlenmeyer flasks 250 or 300 ml.
2. Magnetic stirring device.
3. Burette 10 ml.

Reagents

1. Potassium hydroxide 0.1 N.
2. Solvent mixture consisting of equal parts by volume of isopropyl alcohol and toluene.
3. Phenolphthalein indicator solution 1.0% in isopropyl alcohol.

Procedure

1. Add indicator solution to required amount of solvent in ratio of 2 ml to 125 ml and neutralize with alkali to a faint but permanent pink color.
2. Determine the sample size from the following table:

Acid value	Mass, g of sample (± 10%), g	Weighing accuracy, ± g
0-1	20	0.05
1-4	10	0.02
4-15	2.5	0.01
15-75	0.5	0.001
75 and over	0.1	0.0002

3. Weigh the specified amount of well-mixed liquid sample into an Erlenmeyer flask.
4. Add 125 ml of neutralized solvent mixture. Be sure that the sample is completely dissolved before titrating. Warming may be necessary in some cases.
5. Shake the sample vigorously while titrating with standard alkali to the first permanent pink color of the same intensity as that of the neutralized solvent before the latter was added to the sample. The color must persist for 30 sec.

Calculations

1. Acid value, mg KOH/g of sample = $\frac{(A - B) \times N \times 56.1}{W}$

Where

A = volume, ml of standard alkali used in the titration

B = volume, ml of standard alkali used in titrating the blank

N = normality of standard alkali

W = mass, grams of sample

To express in terms of free fatty acids as percent oleic, lauric or palmitic, divide the acid value by 1.99, 2.81 or 2.19, respectively.

A-3 Saponification Value, AOCS Official Method Cd 3b-76

The saponification value is the amount of alkali necessary to saponify a define quantity of the sample. It is expressed as the number of milligrams of potassium hydroxide (KOH) required to saponify 1 gram of the sample.

Apparatus

1. Erlenmeyer flasks alkali resistant, 250 or 300 ml, with 24/40 ground-glass joint.
2. Air condensers minimum 65 cm long, with 24/20 ground-glass joint to fit Erlenmeyer flasks.
3. Water bath or a hot plate with variable heat control.

Reagents

1. Hydrochloric acid 0.5 N, accurately standardized.
2. Alcoholic potassium hydroxide.
3. Phenolphthalein indicator solution 1.0% in 95% ethyl alcohol.
4. Toluene reagent grade.

Procedure

1. Heat the sample at 100°C until liquid and then mix thoroughly.
2. Accurate weigh about 2g ± 0.1 mg of the melted sample into the Erlenmeyer flask.
3. Add 25 ml of toluene and heat gently to dissolve the sample.
4. Add 50 ml of the alcoholic KOH with a pipet and allow the pipet to drain for a definite period of time
5. Prepare and conduct blank determinations simultaneously with the sample and similar in all respects, except omitting the fat or oil.
6. Add several boiling chips to the flask and connect the air condenser. Boil gently, but steadily, until the sample is completely saponified. This usually requires about 1 hr for normal samples. Make certain that the

vapor ring in the condenser does not rise to the top of the condenser, or loss may occur.

7. After the flask and condenser have cooled somewhat, but not sufficiently to form a gel, wash down the inside of the condenser with a small quantity of distilled water. Disconnect the condenser, add about 1 ml of phenolphthalein indicator and titrate with 0.5 N HCL until the pink color just disappears. Record the volume of 0.5 N HCL required for the titration.

Calculations

$$\text{Saponification value} = \frac{(B-S)\times(N)}{W}\times 56.1$$

Where

B	=	ml 0.5 N HCL required to titrate blank
S	=	ml 0.5 N HCL required to titrate sample
N	=	normality of HCL solution
W	=	weight of sample in grams

Additional information

For the determination of the mean molecular weight of the fatty acids present in a fat the following methods may be used:

1. Assuming the fat to consist of a mixture of triglycerides and free fatty acids and fixed and free fatty acids to have the same mean molecular weight, an apparent value for the mean molecular weight of the fatty acid (M) may be calculated:

$$M = \frac{56108-12.67(SV-AV)}{SV}$$

Where:

SV	=	saponification value of the fat
AV	=	acid value of the fat

2. The mean molecular weight of the water-insoluble fatty acids (M) is calculated:

$$M = \frac{56108}{\text{SV of fatty acids}}$$

3. In 1 and 2 the unsaponifible is included in M.

The true mean molecular weight of the water insoluble fatty acids is determined by saponification of the fat, extraction of the unsaponifiable matter, separation of the fatty acids and determination of their saponification value:

$$M = \frac{56108}{\text{SV of fatty acids}}$$

A-4 Calculation molecular weight of palm olein

Calculation

Let;

Weight (in g.) of oil or fat taken = W

Volume (in ml.) of hydrochloric acid used in test = V_1

Volume (in ml.) of hydrochloric acid used in blank = V_2

Normality of hydrochloric acid = N

$$\text{Saponification value (S.V.)} = \frac{56.1 \times N \times (V_2 - V_1)}{W}$$

$$\text{S.V.} = \frac{56.1 \times 0.5 \times (22 - 7.9)}{2.013}$$

$$= 196.47$$

The mean molecular weight of the fatty acids (M) may be calculated:

$$M = \frac{56108 - 12.67(SV - AV)}{SV}$$

$$= \frac{56108 - (12.67)(196.47 - 0.86)}{196.47}$$

$$= 281.78$$

$$3M.W. = 845.33$$

A-5 Calculation molecular weight of palm stearin

Calculation

Let;

Weight (in g.) of oil or fat taken = W

Volume (in ml.) of hydrochloric acid used in test = V_1

Volume (in ml.) of hydrochloric acid used in blank = V_2

Normality of hydrochloric acid = N

$$\text{Saponification value (S.V.)} = \frac{56.1 \times N \times (V_2 - V_1)}{W}$$

$$S.V. = \frac{56.1 \times 0.5 \times (22 - 8.0)}{2.031}$$

$$= 193.35$$

The mean molecular weight of the fatty acids (M) may be calculated:

$$M = \frac{56108 - 12.67(SV - AV)}{SV}$$

$$= \frac{56108 - (12.67)(193.35 - 0.71)}{193.35}$$

$$= 277.56$$

$$3M.W. = 832.68$$

A-6 Calculation molecular weight of used palm olein

Calculation

Let;

Weight (in g.) of oil or fat taken = W

Volume (in ml.) of hydrochloric acid used in test = V_1

Volume (in ml.) of hydrochloric acid used in blank = V_2

Normality of hydrochloric acid = N

$$\text{Saponification value (S.V.)} = \frac{56.1 \times N \times (V_2 - V_1)}{W}$$

$$\text{S.V.} = \frac{56.1 \times 0.5 \times (21.5 - 7.1)}{2.012}$$

$$= 200.76$$

The mean molecular weight of the fatty acids (M) may be calculated:

$$M = \frac{56108 - 12.67(SV - AV)}{SV}$$

$$= \frac{56108 - (12.67)(200.76 - 2.05)}{200.76}$$

$$= 266.93$$

$$3M.W. = 800.81$$

APPENDIX B

CALCULATION OF RESIDUE CATALYSTS, SOAPS AND PERCENTAGE OF BIODIESEL

B-1 Soap in oil (titrimetric method), AOCS Recommended Practic Cc 17-79

Apparatus

1. Erlenmeyer flask 500 ml.
2. Buret 10 ml, graduated in 0.05 ml units.

Reagents

1. Acetone containing 2% water, prepared by adding 20 ml distilled water to 980 ml of reagent grade acetone.
2. Hydrochloric acid (HCL) approximately 0.01 N, accurately standardized.
3. Bromophenol blue indicator solution 0.4% in water.

Procedure

1. Place 100 ml of acetone-water solution into a 500 ml Erlenmeyer flask. Add 0.5 ml of the bromophenol blue indicator solution.
2. Neutralize the acetone-water mixture by titrating to the yellow end point with 0.01 N HCL.
3. Add approximately 100 ± 0.1 g of melted and well-mixed sample to the neutralized solution.
4. Titrate to the yellow end point with 0.01 N HCL.

Calculations

1. Soap (as sodium oleate)

$$\text{ppm} = \frac{\text{ml} \times (\text{N}) \times 304{,}400}{\text{sample wt, g}}$$

where

ml = ml HCL obtained in Procedure, 4

N = normality of HCL

B-2 Soap in oil, Modified Version of AOCS Method Cc 17-79

The following procedure is a modified version of AOCS method Cc 17-79, soap in oil.

Procedure

1. Dissolve sample in 100 ml of acetone containing 2% distilled water. The amount of sample will depend on the expected level of catalyst and soap. Use 0.5 g of sample for crude glycerol, 5 g of sample for unwashed methyl esters, and 100 g of sample for washed methyl esters.
2. Add 2 ml of 1% phenolphthalein indicator (in isopropyl alcohol).
3. Titrate with 0.1 N hydrochloric acid until you get the phenolphthalein color change (red to clear). This indicates that you have neutralized the free catalyst in sample. Designate this amount of solution as "A".
4. Add 1 ml of bromophenol blue indicator (0.4% in water). This indicator changes color at about pH = 4.5.
5. Titrate until the bromophenol changes from blue to yellow. This indicates that the pH is low enough that all of soap should have been split into FFA and salt. The strong acid we are adding (hydrochloric) is more strongly attracted to the metal ion on the soap than the fatty acid chain. So, the metal ion combines with the CL from the hydrochloric acid to procuce NaCL or KCL, and the hydrogen freed from the hydrochloric acid converts the fatty acid chain to a free fatty acid. Designate this quantity of solution as "B".

Calculations

Now, the amount of HCL added during the first titration tells us how much free catalyst is in the sample and the amount added during the second titration tells us the amount of soap.

$$\text{weight \% of catalyst} = \frac{Q_1 \times 0.1 \times M_1}{1000 \times W} \times 100$$

where

Q_1 = ml of HCL or KOH titrate

M_1 = molecular weight of catalyst

W = grams of sample

This gives the amount of free catalyst in the sample, done here assuming the catalyst was KOH. You can substitute the appropriate molecular weight for other catalysts (KOH = 56.1, NaOH = 40.0, $NaOCH_3$ = 54.03)

$$\text{weight \% of soap} = \frac{Q_2 \times 0.1 \times M_2}{1000 \times W} \times 100$$

where

Q_2 = ml of HCL titrate

M_2 = molecular weight of soap

W = grams of sample

This often expressed as ppm, so this number should be multiplied by one million. This calculation assumed the soap was sodium palmitate. When using sodium catalysts, the molecular weight of sodium palmitate is 286.35 g/mole. Palmitic acid is a pretty good average compound for palm oil. When using potassium hydroxide as catalyst, the molecular weight of potassium palmitate is 297.53 g/mole.

B-3 Calculation percentage of residue catalyst and soap in sample

Calculation

Example calculation in experiment 1.

Lets:

Q_1 = ml of HCL or KOH titrate

M_1 = molecular weight of catalyst

W = grams of sample

$$\text{weight \% of catalyst} = \frac{Q_1 \times 0.1 \times M_1}{1000 \times W} \times 100$$

$$= \frac{1.9 \times 0.1 \times 56.1}{1000 \times 0.501} \times 100$$

$$= 2.127$$

Q_2 = ml of HCL titrate

M_2 = molecular weight of soap

W = grams of sample

$$\text{weight \% of soap} = \frac{0.9 \times 0.1 \times 297.53}{1000 \times 0.501} \times 100$$

$$= 5.345$$

B-4 Response factor of methyl esters and fatty acids

The response factor is defined as

$$\text{R.F} = \frac{\text{Area of methyl esters or fatty acids} \times \text{g of internal standard in solution}}{\text{Area of internal standard} \times \text{g of methyl esters or fatty acids}}$$

Response factor calculations are based on the data from the chromatogram of standard methyl esters and fatty acids.

$$\text{Response factor of methyl myristate} = \frac{6.6526 \times 0.0711}{3.5916 \times 0.0968}$$

$$\text{R.F}_{\text{methyl myristate}} = 1.3601 \sim 1.36$$

$$\text{Response factor of methyl palmitate} = \frac{5.4610 \times 0.0711}{3.4754 \times 0.0959}$$

$$\text{R.F}_{\text{methyl palmitate}} = 1.1652 \sim 1.16$$

$$\text{Response factor of methyl stearate} = \frac{5.7430 \times 0.0710}{3.5511 \times 0.1033}$$

$$\text{R.F}_{\text{methyl stearate}} = 1.1103 \sim 1.11$$

$$\text{Response factor of methyl oleate} = \frac{5.9501 \times 0.0712}{3.8526 \times 0.0909}$$

$$\text{R.F}_{\text{methyl oleate}} = 1.2094 \sim 1.21$$

Response factor of methyl linoleate $= \frac{11.1569 \times 0.0720}{5.8254 \times 0.0924}$

$R.F_{\text{methyl linoleate}} = 1.4910 \sim 1.49$

Response factor of palmitic acids $= \frac{7.2170 \times 0.0710}{4.9466 \times 0.0976}$

$R.F_{\text{palmitic acids}} = 1.0694 \sim 1.07$

Response factor of stearic acids $= \frac{5.2598 \times 0.0709}{4.2328 \times 0.1002}$

$R.F_{\text{stearic acid acids}} = 0.8788 \sim 0.88$

Response factor of oleic acids $= \frac{4.5322 \times 0.0709}{3.4369 \times 0.0933}$

$R.F_{\text{oleaic acids}} = 1.0015 \sim 1.00$

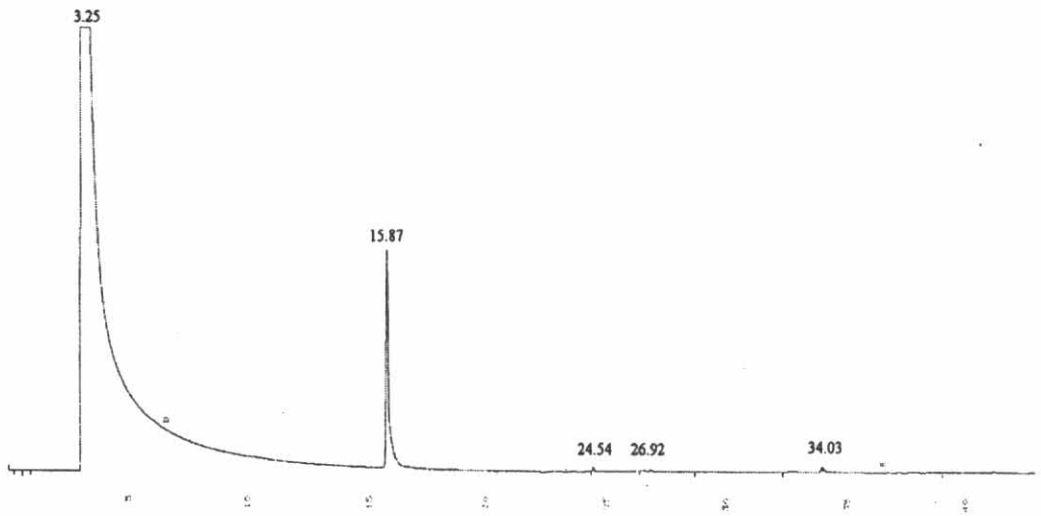
B-5 Analysis of methyl ester

Analysis of methyl esters and fatty acids in product by used gas chromatography (GC). The retention time of each methyl esters are different. Therefore, for find the type of methyl ester by compare retention time of each methyl ester with methyl ester standard. The retention time are shown in Table B-1.

Table B-1 Retention time of methyl esters and fatty acids in GC chromatogram

Number of peak	Retention time (min)	Peak of sample
1	3.25	N-heptane
2	22.19	Methyl myristate
3	24.54	Methyl palmitate
4	26.66	Methyl stearate
5	26.92	Methyl oleate
6	27.45	Methyl linoleate
7	34.03	Palmitic acid
8	39.97	Stearic acid
9	41.29	Oleic acid

B-6 GC chromatogram of biodiesel from experiment



RT	AREA	BC	AREA%
3.25	126.5582		95.6784
15.87	4.9709	V	3.7580
24.54	0.2793	T	0.2112
26.92	0.4658	T	0.3521
34.03	0.0004		0.0759
3 PEAKS	>	AREA/HT	REJECT

Figure B-1 Chromatogram for methyl esters at condition: Palm olein reactant, 6:1 molor ratio of methanol to oil, 1% H_2SO_4, 120 min and 60°C

Example1. From figure B-1, find concentration of methyl esters at 100 % mole of excess methanol from its stoichiometic ratio, temperature of 60 °C, 120 min using acid catalyst. Product of 0.1004 added to 1.5078 g of methyl decanoate solution.

Note that: In methyl decanoate solution 1.5078 g has 0.0720 g of methyl decanoate.

$$\%\text{Methyl esters or free fatty acids} = \frac{\text{g of total methyl esters or fatty acids}}{\text{g of sample}} \times 100$$

$$\text{g of methyl esters} = \frac{\text{Area of methyl esters}}{\text{Area of internal standard}} \times \frac{\text{g of internal standard in solution}}{\text{R.F. of methyl esters}}$$

$$\text{g of methyl palmitate} = \frac{0.2793}{4.9709} \times \frac{0.0720}{1.16}$$

$$= 0.0035$$

$$\text{g of methyl oleate} = \frac{0.4658}{4.9709} \times \frac{0.0720}{1.21}$$

$$= 0.0056$$

Also; $\text{g of total methyl esters} = 0.0035 + 0.0056$

$$= 0.0091$$

$$\%\text{Methyl esters} = \frac{0.0091}{0.1004} \times 100$$

$$= 9.0397\,\% \sim 9.04$$

APPENDIX C

EXPERIMENTAL DATA OF TRANSESTERIFICATION USING BASIC AND ACID CATALYSTS AND DATA OF SAMPLE FROM INDUSTRIAL SCALE

Table C-1 Details in each experiment

Exp. No.	Raw Material						Temp (°C)	Time (hr)
	Oil			Catalyst		Methanol (g)		
	Type	Weight(g)	%FFA	Type	Weight(g)			
1	Palm olein	500	0.31	KOH	2.527	113.6	60-65	2
2	Palm olein (repeat 1)	501	0.31	KOH	2.503	113.5	60-65	2
3	Palm olein (repeat 2)	501	0.32	KOH	2.511	113.5	60-65	2
4	Palm olein	501	0.31	KOH	5.032	113.5	60-65	2
5	Palm olein (repeat 1)	500	0.32	KOH	5.036	113.6	60-65	2
6	Palm olein (repeat 2)	500	0.32	KOH	5.028	113.6	60-65	2
7	Palm Stearin	501	0.21	KOH	2.521	113.5	60-65	2
8	Palm Stearin (repeat 1)	501	0.22	KOH	2.514	113.5	60-65	2

Table C-2 Details in each experiment

Exp. No.	Raw Material						Temp. (°C)	Time (hr)
	Oil			Catalyst		Methanol (g)		
	Type	Weight (g)	%FFA	Type	Weight (g)			
9	Palm Stearin (repeat 2)	501	0.21	KOH	2.519	113.6	60-65	2
10	Palm Stearin	500	0.21	KOH	5.045	113.6	60-65	2
11	Palm Stearin (repeat 1)	500	0.21	KOH	5.037	113.5	60-65	2
12	Palm Stearin (repeat 2)	501	0.21	KOH	5.072	113.5	60-65	2
13	Used Palm Olein	501	1.29	KOH	4.302	113.6	60-65	2
14	Used Palm Olein (repeat 1)	501	1.29	KOH	4.305	113.6	60-65	2
15	Used Palm Olein (repeat 2)	500	1.29	KOH	4.303	113.5	60-65	2
16	Used Palm Olein	500	1.29	KOH	6.810	113.6	60-65	2
17	Used Palm Olein (repeat 1)	500	1.29	KOH	6.805	113.6	60-65	2
18	Used Palm Olein (repeat 2)	501	1.29	KOH	6.804	113.6	60-65	2
19	Palm olein	500	0.31	H_2SO_4	2.502	113.5	60-65	2
20	Palm olein (repeat 1)	500	0.31	H_2SO_4	2.513	113.5	60-65	2
21	Palm olein (repeat 2)	501	0.31	H_2SO_4	2.515	113.5	60-65	2
22	Palm olein	500	0.32	H_2SO_4	5.057	113.6	60-65	2
23	Palm olein (repeat 1)	501	0.31	H_2SO_4	5.021	113.6	60-65	2

Table C-3 Details in each experiment

Exp. No.	Raw Material						Temp. (°C)	Time (hr)
	Oil			Catalyst		Methanol (g)		
	Type	Weight (g)	%FFA	Type	Weight (g)			
24	Palm olein (repeat 2)	501	0.31	H_2SO_4	5.043	113.5	60-65	2
25	Palm Stearin	501	0.21	H_2SO_4	2.511	113.6	60-65	2
26	Palm Stearin (repeat 1)	501	0.21	H_2SO_4	2.516	113.6	60-65	2
27	Palm Stearin (repeat 2)	501	0.21	H_2SO_4	2.506	113.5	60-65	2
28	Palm Stearin	500	0.21	H_2SO_4	5.032	113.6	60-65	2
29	Palm Stearin (repeat 1)	501	0.22	H_2SO_4	5.053	113.6	60-65	2
30	Palm Stearin (repeat 2)	501	0.22	H_2SO_4	5.043	113.6	60-65	2
31	Used Palm Olein	502	1.29	H_2SO_4	2.515	113.5	60-65	2
32	Used Palm Olein (repeat 1)	501	1.29	H_2SO_4	2.508	113.5	60-65	2
33	Used Palm Olein (repeat 2)	501	1.29	H_2SO_4	2.511	113.5	60-65	2
34	Used Palm Olein	501	1.29	H_2SO_4	5.045	113.6	60-65	2
35	Used Palm Olein (repeat 1)	501	1.29	H_2SO_4	5.073	113.6	60-65	2
36	Used Palm Olein (repeat 2)	501	1.29	H_2SO_4	5.105	113.5	60-65	2
-	Palm Stearin Industrial Scale	18000 (l)	0.2	NaOH	79.2 (kg)	4000 (l)	60	1
-	Palm Stearin Industrial Scale	18000 (l)	0.2	NaOH	79.2 (kg)	4000 (l)	60	1

Table C-4 Details in each experiment

Exp. No.	Raw Material						Temp. (°C)	Time (hr)
	Oil			Catalyst		Methanol (g)		
	Type	Weight (g)	%FFA	Type	Weight (g)			
-	Palm Stearin Industrial Scale	18000 (l)	0.2	NaOH	79.2 (kg)	4000 (l)	60	1
-	Palm Stearin Industrial Scale	18000 (l)	0.2	NaOH	79.2 (kg)	4000 (l)	60	1
-	Palm Stearin Industrial Scale	18000 (l)	0.2	NaOH	79.2 (kg)	4000 (l)	60	1
37	Palm Stearin	500	0.22	NaOH	1.790	86.2	60	1
38	Palm Stearin (repeat 1)	500	0.22	NaOH	1.751	86.1	60	1
39	Palm Stearin (repeat 2)	501	0.23	NaOH	1.765	86.1	60	1
-	Palm Olein + Palm Stearin, Industrial Scale	-	-	$NaOCH_3$	-	-	-	-
-	Palm Olein + Palm Stearin, Industrial Scale	-	-	$NaOCH_3$	-	-	-	-
40	Palm Olein + Palm Stearin	500	0.26	$NaOCH_3$	2.514	113.5	60-65	2
41	Palm Olein + Palm Stearin (repeat 1)	501	0.26	$NaOCH_3$	2.543	113.5	60-65	2
42	Palm Olein + Palm Stearin (repeat 2)	500	0.26	$NaOCH_3$	2.525	113.4	60-65	2
43	Palm Olein + Palm Stearin	501	0.26	$NaOCH_3$	5.018	113.6	60-65	2
44	Palm Olein + Palm Stearin (repeat 1)	501	0.26	$NaOCH_3$	5.006	113.5	60-65	2
45	Palm Olein + Palm Stearin (repeat 2)	501	0.26	$NaOCH_3$	5.021	113.6	60-65	2

Table C-5 Amount of crude glycerol, crude biodiesel and methanol in each experiment

Exp. No.	Glycerol fraction						Biodiesel fraction					
	Crude glycerol (g)	pH	Crude glycerol after remove methanol (g)	pH	Methanol (g)	pH	Crude biodiesel (g)	pH	Crude biodiesel after remove methanol (g)	pH	Methanol (g)	pH
1	95.8	10	64.7	10	30.198	6	505	8	496	8	8.543	6
2	96.1	10	64.9	10	30.235	6	505	8	495	8	8.735	6
3	95.9	10	64.7	10	30.210	6	505	8	496	8	8.504	6
4	105.4	11	73.2	11	30.583	6	495	10	486	10	8.114	6
5	105.6	11	73.4	11	30.605	6	495	10	486	10	8.243	6
6	105.6	11	73.3	11	30.612	6	496	10	487	10	8.175	6
7	94.8	10	64.2	10	30.213	6	506	8	495	8	9.843	6
8	94.5	10	64.2	10	30.251	6	506	8	496	8	9.115	6
9	94.7	10	64.4	10	30.275	6	505	8	495	8	9.235	6
10	102.1	11	72.7	11	30.302	6	496	10	487	10	8.042	6
11	102.3	11	72.8	11	30.411	6	496	10	487	10	8.135	6
12	101.9	11	72.8	11	30.384	6	496	10	487	10	8.108	6
13	111.2	10	79.7	10	30.245	6	498	8	488	8	9.014	6
14	111.1	10	80.1	10	30.251	6	498	8	487	8	9.156	6

Table C-6 Amount of crude glycerol, crude biodiesel and methanol in each experiment

Exp. No.	Glycerol fraction						Biodiesel fraction					
	Crude glycerol (g)	pH	Crude glycerol after remove methanol (g)	pH	Methanol (g)	pH	Crude biodiesel (g)	pH	Crude biodiesel after remove methanol (g)	pH	Methanol (g)	pH
15	110.9	10	79.8	10	30.228	6	498	8	488	8	9.113	6
16	121.3	11	91.2	11	29.352	6	484	10	475	10	8.754	6
17	121.2	11	91.3	11	29.075	6	484	10	475	10	8.742	6
18	121.2	11	91.3	11	29.104	6	485	10	475	10	8.675	6
19	60.9	3	19.2	3	41.547	6	512	4	502	4	9.331	6
20	61.4	3	18.8	3	42.534	6	512	4	501	4	9.825	6
21	61.4	3	19.0	3	41.933	6	512	4	501	4	9.722	6
22	63.6	3	25.6	3	37.773	6	509	3	499	3	9.553	6
23	63.5	3	25.7	3	38.875	6	510	3	499	3	9.874	6
24	63.6	3	25.5	3	38.455	6	510	3	500	3	9.243	6
25	60.6	3	18.8	3	41.104	6	511	4	502	4	8.353	6
26	60.8	3	18.6	3	40.578	6	512	4	502	4	8.949	6
27	60.8	3	18.6	3	40.741	6	512	4	502	4	8.871	6
28	63.2	3	25.6	3	36.815	6	510	3	499	3	9.533	6

Table C-7 Amount of crude glycerol, crude biodiesel and methanol in each experiment

Exp. No.	Glycerol fraction						Biodiesel fraction					
	Crude glycerol (g)	pH	Crude glycerol after remove methanol (g)	pH	Methanol (g)	pH	Crude biodiesel (g)	pH	Crude biodiesel after remove methanol (g)	pH	Methanol (g)	pH
29	63.1	3	25.5	3	36.525	6	510	3	499	3	10.264	6
30	63.2	3	25.6	3	36.613	6	510	3	498	3	10.452	6
31	73.2	3	26.1	3	46.822	6	502	4	491	4	10.575	6
32	73.4	3	25.9	3	46.856	6	502	4	490	4	10.617	6
33	73.4	3	25.7	3	46.792	6	502	4	490	4	10.645	6
34	75.1	3	37.8	3	36.578	6	499	3	488	3	10.231	6
35	74.7	3	38.1	3	36.054	6	499	3	488	3	10.312	6
36	74.8	3	38.0	3	36.115	6	500	3	489	3	10.256	6
-	110.1	10	88.4	10	18.883	6	500	8	493	8	7.581	6
-	109.8	10	88.5	10	19.250	6	500	8	494	8	7.526	6
-	110.0	10	88.6	10	19.283	6	501	8	493	8	7.707	6
-	110.1	10	88.7	10	19.311	6	501	8	493	8	7.532	6
-	109.9	10	88.7	10	19.318	6	501	8	493	8	7.416	6
37	69.3	10	58.2	10	10.543	6	501	8	496	8	4.675	6

Table C-8 Amount of crude glycerol, crude biodiesel and methanol in each experiment

Exp. No.	Glycerol fraction						Biodiesel fraction					
	Crude glycerol (g)	pH	Crude glycerol after remove methanol (g)	pH	Methanol (g)	pH	Crude biodiesel (g)	pH	Crude biodiesel after remove methanol (g)	pH	Methanol (g)	pH
38	69.5	10	59.1	10	9.724	6	501	8	496	8	4.659	6
39	69.5	10	58.7	10	10.012	6	501	8	495	8	5.133	6
-	150.4	10	118.3	10	29.257	6	500	9	487	9	10.910	6
-	150.3	10	118.1	10	29.314	6	500	9	487	9	10.895	6
40	85.4	10	53.8	10	31.021	6	512	8	498	8	13.341	6
41	85.6	10	53.8	10	31.017	6	511	8	498	8	13.337	6
42	85.5	10	53.7	10	31.019	6	511	8	498	8	13.340	6
43	113.1	11	82.2	11	30.423	6	499	10	493	10	5.151	6
44	113.3	11	82.2	11	30.419	6	498	10	493	10	4.544	6
45	113.3	11	82.3	11	30.421	6	498	10	493	10	4.513	6

Table C-9 Amount of methanol and percentage of methanol in each phase of reaction products

Exp.No.	Amount of input methanol (g)	Crude glycerol phase		Crude biodiesel phase	
		Amount of methanol (g)	%wt of methanol by weight of input methanol	Amount of methanol (g)	%wt of methanol by weight of input methanol
1	113.6	30.198	26.58	8.543	7.52
2	113.5	30.235	26.64	8.735	7.70
3	113.5	30.210	26.62	8.504	7.49
4	113.5	30.583	26.95	8.114	7.15
5	113.6	30.605	26.94	8.243	7.26
6	113.6	30.612	26.95	8.175	7.20
7	113.5	30.213	26.62	9.843	8.67
8	113.5	30.251	26.65	9.115	8.03
9	113.6	30.275	26.65	9.235	8.13
10	113.6	30.302	26.67	8.042	7.08
11	113.5	30.411	26.79	8.135	7.17
12	113.5	30.384	26.77	8.108	7.14
13	113.6	30.245	26.62	9.014	7.93
14	113.6	30.251	26.63	9.156	8.06
15	113.5	30.228	26.63	9.113	8.03
16	113.6	29.352	25.84	8.754	7.71
17	113.6	29.075	25.59	8.742	7.70
18	113.6	29.104	25.62	8.675	7.64
19	113.5	41.547	36.61	9.331	8.22
20	113.5	42.534	37.47	9.825	8.66
21	113.5	41.933	36.95	9.722	8.57

Table C-10 Amount of methanol and percentage of methanol in each phase of reaction products

Exp.No.	Amount of input methanol (g)	Crude glycerol phase		Crude biodiesel phase	
		Amount of methanol (g)	%wt of methanol by weight of input methanol	Amount of methanol (g)	%wt of methanol by weight of input methanol
22	113.6	37.773	33.25	9.553	8.41
23	113.6	38.875	34.22	9.874	8.69
24	113.5	38.455	33.88	9.243	8.14
25	113.6	41.104	36.18	8.353	7.35
26	113.6	40.578	35.72	8.949	7.88
27	113.5	40.741	35.90	8.871	7.82
28	113.6	36.815	32.41	9.533	8.39
29	113.6	36.525	32.15	10.264	9.04
30	113.6	36.613	32.23	10.452	9.20
31	113.5	46.822	41.25	10.575	9.32
32	113.5	46.856	41.28	10.617	9.35
33	113.5	46.792	41.23	10.645	9.38
34	113.6	36.578	32.20	10.231	9.01
35	113.6	36.054	31.74	10.312	9.08
36	113.5	36.115	31.82	10.256	9.04
37	86.2	10.543	12.23	4.675	5.42
38	86.1	9.724	11.29	4.659	5.41
39	86.1	10.012	11.63	5.133	5.96
40	113.5	31.021	27.33	13.341	11.75
41	113.5	31.017	27.33	13.337	11.75
42	113.4	31.019	27.35	13.340	11.76

Table C-11 Amount of methanol and percentage of methanol in each phase of reaction products

Exp.No.	Amount of input methanol (g)	Crude glycerol phase		Crude biodiesel phase	
		Amount of methanol (g)	%wt of methanol by weight of input methanol	Amount of methanol (g)	%wt of methanol by weight of input methanol
43	113.6	30.423	26.78	5.151	4.53
44	113.5	30.419	26.80	4.544	4.00
45	113.6	30.421	26.78	4.513	3.97

Table C-12 Amount of wash water and refined biodiesel in each experiment

Exp. No.	Wash water 1				Wash water 2				Total wash water			Refined Biodiesel	
	In (g)	pH	Out (g)	pH	In (g)	pH	Out (g)	pH	In (g)	Out (g)	pH	Weight (g)	pH
1	148.5	6-7	143.4	8	-	-	-	-	148.5	143.4	8	439	6
2	147.9	6-7	143.1	8	-	-	-	-	147.9	143.1	8	439	6
3	148.2	6-7	144.4	8	-	-	-	-	148.2	144.4	8	440	6
4	142.1	6-7	139.8	10	142.3	6-7	144.2	7	284.4	284	10	423	6
5	142.3	6-7	140.2	10	141.8	6-7	143.3	7	284.1	283.5	10	424	6
6	141.5	6-7	139.7	10	141.6	6-7	142.2	7	283.1	281.9	10	423	6
7	148.8	6-7	142.5	8	-	-	-	-	148.8	142.5	8	439	6
8	147.5	6-7	142.1	8	-	-	-	-	147.5	142.1	8	439	6
9	147.9	6-7	144.3	8	-	-	-	-	147.9	144.3	8	440	6
10	142.3	6-7	140.8	10	142.3	6-7	143.8	7	284.6	284.6	10	423	6
11	142.2	6-7	139.2	10	142.1	6-7	144.3	7	284.3	283.5	10	424	6
12	142.1	6-7	139.7	10	141.8	6-7	144.2	7	283.9	283.9	10	423	6
13	144.5	6-7	141.2	8	-	-	-	-	144.5	141.2	8	429	6
14	144.7	6-7	140.9	8	-	-	-	-	144.7	140.9	8	430	6

Table C-13 Amount of wash water and refined biodiesel in each experiment

Exp. No.	Wash water 1				Wash water 2				Total wash water			Refined Biodiesel	
	In (g)	pH	Out (g)	pH	In (g)	pH	Out (g)	pH	In (g)	Out (g)	pH	Weight (g)	pH
15	144.9	6-7	141.4	8	-	-	-	-	144.9	141.4	8	431	6
16	138.1	6-7	136.6	10	138.3	6-7	139.2	7	276.4	275.8	10	411	6
17	137.9	6-7	136.1	10	137.7	6-7	137.8	7	275.6	273.9	10	412	6
18	138.3	6-7	135.9	10	138.1	6-7	138.3	7	276.4	274.2	10	411	6
19	151.8	6-7	149.5	4	-	-	-	-	151.8	149.5	4	451	6
20	151.5	6-7	149.3	4	-	-	-	-	151.5	149.3	4	451	6
21	151.9	6-7	149.8	4	-	-	-	-	151.9	149.8	4	452	6
22	150.2	6-7	148.2	3	150.3	6-7	151.4	5	300.5	299.6	4	447	6
23	149.8	6-7	147.8	3	150.1	6-7	152.2	5	299.9	300.0	4	446	6
24	149.7	6-7	147.5	3	149.9	6-7	150.8	5	299.6	298.3	4	446	6
25	152.8	6-7	150.8	4	-	-	-	-	152.8	150.8	4	455	6
26	152.5	6-7	150.3	4	-	-	-	-	152.5	150.3	4	454	6
27	152.7	6-7	150.1	4	-	-	-	-	152.7	150.1	4	454	6
28	149.5	6-7	147.3	3	149.7	6-7	150.3	5	299.2	297.6	4	445	6

Table C-14 Amount of wash water and refined biodiesel in each experiment

Exp. No.	Wash water 1				Wash water 2				Total wash water			Refined Biodiesel	
	In (g)	pH	Out (g)	pH	In (g)	pH	Out (g)	pH	In (g)	Out (g)	pH	Weight (g)	pH
29	150.1	6-7	147.8	3	150.3	6-7	151.4	5	300.4	299.2	4	446	6
30	149.8	6-7	147.5	3	150.3	6-7	151.2	5	300.1	298.7	4	446	6
31	147.1	6-7	145.1	4	-	-	-	-	147.1	145.1	4	438	6
32	147.3	6-7	145.2	4	-	-	-	-	147.3	145.2	4	438	6
33	147.2	6-7	144.8	4	-	-	-	-	147.2	147.2	4	438	6
34	146.5	6-7	144.7	3	146.8	6-7	149.0	5	293.3	293.7	4	436	6
35	146.4	6-7	144.4	3	146.5	6-7	149.3	5	292.9	293.7	4	436	6
36	146.5	6-7	144.3	3	146.7	6-7	149.2	5	293.2	293.5	4	436	6
-	147.5	6-7	143.2	8	-	-	-	-	147.5	143.2	8	439	6
-	148.1	6-7	143.4	8	-	-	-	-	148.1	143.4	8	440	6
-	147.3	6-7	144.1	8	-	-	-	-	147.3	144.1	8	438	6
-	147.7	6-7	144.2	8	-	-	-	-	147.7	144.2	8	438	6
-	147.5	6-7	144.4	8	-	-	-	-	147.5	144.4	8	439	6
37	148.3	6-7	145.9	8	-	-	-	-	148.3	145.9	8	439	6

Table C-15 Amount of wash water and refined biodiesel in each experiment

Exp. No.	Wash water 1				Wash water 2				Total wash water			Refined Biodiesel	
	In (g)	pH	Out (g)	pH	In (g)	pH	Out (g)	pH	In (g)	Out (g)	pH	Weight (g)	pH
38	148.5	6-7	145.9	8	-	-	-	-	148.5	145.9	8	440	6
39	148.5	6-7	146.1	8	-	-	-	-	148.5	146.1	8	439	6
-	145.1	6-7	140.3	9	145.3	6-7	147.7	7	290.4	288.0	9	433	6
-	145.3	6-7	140.6	9	145.5	6-7	148.2	7	290.8	288.8	9	435	6
40	148.7	6-7	145.3	8	-	-	-	-	148.7	145.3	8	440	6
41	149.0	6-7	145.5	8	-	-	-	-	149.0	145.5	8	441	6
42	148.7	6-7	145.2	8	-	-	-	-	148.7	145.2	8	440	6
43	146.9	6-7	143.5	10	146.8	6-7	147.2	7	293.7	290.7	10	435	6
44	146.8	6-7	143.3	10	146.8	6-7	147.4	7	293.6	290.7	10	436	6
45	146.5	6-7	143.7	10	146.5	6-7	147.4	7	293	291.1	10	436	6

Table C-16 Percent of residue catalysts and soaps in each phase of reaction products of basic and acid transesterification experiment

Exp. No.	Residue catalysts (%wt)				Soaps (%wt)			
	Crude Glycerol	Crude Biodiesel	Refined Biodiesel	Wash Water	Crude Glycerol	Crude Biodiesel	Refined Biodiesel	Wash Water
1	2.13	0.074	-	0.028	5.34	0.060	-	0.098
2	2.13	0.074	-	0.028	5.34	0.060	-	0.098
3	2.13	0.074	-	0.028	5.34	0.060	-	0.099
4	3.51	0.153	-	0.057	5.54	0.059	-	0.105
5	3.51	0.153	-	0.057	5.54	0.060	-	0.105
6	3.51	0.152	-	0.057	5.54	0.060	-	0.105
7	2.12	0.073	-	0.028	5.34	0.060	-	0.098
8	2.12	0.072	-	0.027	5.33	0.060	-	0.098
9	2.12	0.073	-	0.028	5.33	0.060	-	0.098
10	3.51	0.152	-	0.056	5.52	0.060	-	0.103
11	3.51	0.152	-	0.056	5.52	0.060	-	0.103
12	3.51	0.152	-	0.057	5.52	0.060	-	0.103
13	2.43	0.127	-	0.032	8.90	0.089	-	0.106

Table C-17 Percent of residue catalysts and soaps in each phase of reaction products of basic and acid transesterification experiment

Exp. No.	Residue catalysts (%wt)				Soaps (%wt)			
	Crude Glycerol	Crude Biodiesel	Refined Biodiesel	Wash Water	Crude Glycerol	Crude Biodiesel	Refined Biodiesel	Wash Water
14	2.43	0.127	-	0.032	8.90	0.089	-	0.106
15	2.43	0.127	-	0.032	8.89	0.089	-	0.106
16	3.75	0.202	-	0.073	9.28	0.089	-	0.105
17	3.75	0.202	-	0.073	9.28	0.089	-	0.106
18	3.75	0.202	-	0.073	9.28	0.089	-	0.106
19	5.30	0.098	-	0.075	-	-	-	-
20	5.30	0.098	-	0.075	-	-	-	-
21	5.30	0.098	-	0.075	-	-	-	-
22	8.85	0.210	-	0.155	-	-	-	-
23	8.85	0.210	-	0.155	-	-	-	-
24	8.84	0.210	-	0.155	-	-	-	-
25	5.24	0.098	-	0.075	-	-	-	-
26	5.25	0.098	-	0.075	-	-	-	-

Table C-18 Percent of residue catalysts and soaps in each phase of reaction products of basic and acid transesterification experiment

Exp. No.	Residue catalysts (%wt)				Soaps (%wt)			
	Crude Glycerol	Crude Biodiesel	Refined Biodiesel	Wash Water	Crude Glycerol	Crude Biodiesel	Refined Biodiesel	Wash Water
27	5.25	0.098	-	0.075	-	-	-	-
28	8.90	0.215	-	0.153	-	-	-	-
29	8.89	0.215	-	0.153	-	-	-	-
30	8.89	0.214	-	0.154	-	-	-	-
31	3.35	0.098	-	0.075	-	-	-	-
32	3.35	0.098	-	0.075	-	-	-	-
33	3.35	0.098	-	0.075	-	-	-	-
34	5.23	0.213	-	0.153	-	-	-	-
35	5.23	0.213	-	0.154	-	-	-	-
36	5.23	0.213	-	0.154	-	-	-	-
-	1.85	0.071	-	0.029	5.14	0.057	-	0.077
-	1.82	0.070	-	0.029	5.14	0.057	-	0.077
-	1.83	0.070	-	0.029	5.14	0.057	-	0.076

Table C-19 Percent of residue catalysts and soaps in each phase of reaction products of basic and acid transesterification experiment

Exp. No.	Residue catalysts (%wt)				Soaps (%wt)			
	Crude Glycerol	Crude Biodiesel	Refined Biodiesel	Wash Water	Crude Glycerol	Crude Biodiesel	Refined Biodiesel	Wash Water
-	1.81	0.070	-	0.029	5.14	0.057	-	0.076
-	1.81	0.071	-	0.029	5.14	0.057	-	0.076
37	1.71	0.069	-	0.029	4.57	0.056	-	0.075
38	1.72	0.068	-	0.029	4.57	0.056	-	0.075
39	1.72	0.068	-	0.029	4.57	0.056	-	0.075
-	2.26	0.073	-	0.028	5.13	0.057	-	0.090
-	2.26	0.073	-	0.028	5.13	0.057	-	0.090
40	2.42	0.072	-	0.028	5.27	0.056	-	0.089
41	2.44	0.072	-	0.028	5.27	0.056	-	0.089
42	2.41	0.072	-	0.028	5.25	0.056	-	0.090
43	3.53	0.159	-	0.029	5.71	0.057	-	0.089
44	3.53	0.159	-	0.029	5.71	0.057	-	0.089
45	3.54	0.159	-	0.029	5.71	0.057	-	0.089

Table C-20 Amount of residue catalysts in glycerol phase of basic and acid transesterification experiment

Exp.No.	Catalyst	Amount of catalyst (g)	Glycerol phase				
			Residue catalysts		Soaps		
			Amount of residue catalyst (g)	% of residue catalyst by weight of input catalyst	Amount of soap (g)	Amount of catalyst reacted with FFA (g)	% of catalyst reacted with FFA by weight of input catalyst
1	KOH	2.527	1.38	54.535	3.45	0.65	25.779
2	KOH	2.503	1.38	55.229	3.47	0.65	26.107
3	KOH	2.511	1.38	54.883	3.45	0.65	25.944
4	KOH	5.032	2.57	51.060	4.06	0.76	15.195
5	KOH	5.036	2.58	51.158	4.07	0.77	15.225
6	KOH	5.028	2.57	51.170	4.06	0.77	15.228
7	KOH	2.521	1.36	53.988	3.43	0.65	25.641
8	KOH	2.514	1.36	54.138	3.42	0.65	25.664
9	KOH	2.519	1.37	54.199	3.43	0.65	25.693
10	KOH	5.045	2.55	50.580	4.01	0.76	14.998
11	KOH	5.037	2.56	50.730	4.02	0.76	15.043
12	KOH	5.072	2.56	50.380	4.02	0.76	14.939
13	KOH	4.302	1.94	45.019	7.09	1.34	31.089
14	KOH	4.305	1.95	45.213	7.13	1.34	31.223
15	KOH	4.303	1.94	45.065	7.09	1.34	31.086
16	KOH	6.810	3.42	50.220	8.46	1.60	23.433
17	KOH	6.805	3.42	50.312	8.47	1.60	23.476
18	KOH	6.804	3.42	50.320	8.47	1.60	23.479

Table C-21 Amount of residue catalysts in glycerol phase of basic and acid transesterification experiment

Exp.No.	Catalyst	Amount of catalyst (g)	Glycerol phase				
			Residue catalyst		Soaps		
			Amount of residue catalyst (g)	% of residue catalyst by weight of input catalyst	Amount of soap (g)	Amount of catalyst reacted with FFA (g)	% of catalyst reacted with FFA by weight of input catalyst
19	H_2SO_4	2.502	1.55	61.855	-	-	-
20	H_2SO_4	2.513	1.53	60.740	-	-	-
21	H_2SO_4	2.515	1.54	61.113	-	-	-
22	H_2SO_4	5.057	3.15	62.302	-	-	-
23	H_2SO_4	5.021	3.16	62.925	-	-	-
24	H_2SO_4	5.043	3.14	62.229	-	-	-
25	H_2SO_4	2.511	1.51	60.100	-	-	-
26	H_2SO_4	2.516	1.50	59.678	-	-	-
27	H_2SO_4	2.506	1.50	59.916	-	-	-
28	H_2SO_4	5.032	3.17	62.965	-	-	-
29	H_2SO_4	5.053	3.16	62.457	-	-	-
30	H_2SO_4	5.043	3.16	62.757	-	-	-
31	H_2SO_4	2.515	1.54	61.406	-	-	-
32	H_2SO_4	2.508	1.54	61.310	-	-	-
33	H_2SO_4	2.511	1.53	60.970	-	-	-
34	H_2SO_4	5.045	3.02	59.920	-	-	-
35	H_2SO_4	5.073	3.04	59.898	-	-	-
36	H_2SO_4	5.105	3.03	59.420	-	-	-

Table C-22 Amount of residue catalysts in glycerol phase of basic and acid transesterification experiment

Exp.No.	Catalyst	Amount of catalyst (g)	Glycerol phase				
			Residue catalyst		Soaps		
			Amount of residue catalyst (g)	% of residue catalyst by weight of input catalyst	Amount of soap (g)	Amount of catalyst reacted with FFA (g)	% of catalyst reacted with FFA by weight of input catalyst
37	NaOH	1.790	1.00	55.599	2.66	0.38	21.507
38	NaOH	1.751	1.02	58.054	2.70	0.39	22.326
39	NaOH	1.765	1.01	57.203	2.68	0.39	21.999
40	$NaOCH_3$	2.514	1.30	51.788	2.84	0.55	22.037
41	$NaOCH_3$	2.543	1.31	51.621	2.84	0.55	21.786
42	$NaOCH_3$	2.525	1.29	51.254	2.82	0.55	21.818
43	$NaOCH_3$	5.018	2.90	57.825	4.69	0.92	18.277
44	$NaOCH_3$	5.006	2.90	57.964	4.69	0.92	18.321
45	$NaOCH_3$	5.021	2.91	58.025	4.70	0.92	18.289

Table C-23 Amount of residue catalysts in biodiesel phase of basic and acid transesterification experiment

Exp.No.	Catalyst	Amount of catalyst (g)	Biodiesel phase				
			Residue catalyst		Soaps		
			Amount of residue catalyst (g)	% of residue catalyst by weight of input catalyst	Amount of soap (g)	Amount of catalyst reacted with FFA (g)	% of catalyst reacted with FFA by weight of input catalyst
1	KOH	2.527	0.37	14.525	0.30	0.06	2.221
2	KOH	2.503	0.37	14.634	0.30	0.06	2.237
3	KOH	2.511	0.37	14.617	0.30	0.06	2.235
4	KOH	5.032	0.74	14.777	0.29	0.05	1.074
5	KOH	5.036	0.74	14.765	0.29	0.05	1.092
6	KOH	5.028	0.74	14.722	0.29	0.06	1.096
7	KOH	2.521	0.36	14.334	0.30	0.06	2.221
8	KOH	2.514	0.36	14.205	0.30	0.06	2.232
9	KOH	2.519	0.36	14.345	0.30	0.06	2.223
10	KOH	5.045	0.74	14.673	0.29	0.06	1.092
11	KOH	5.037	0.74	14.696	0.29	0.06	1.094
12	KOH	5.072	0.74	14.595	0.29	0.06	1.086
13	KOH	4.302	0.62	14.406	0.43	0.08	1.904
14	KOH	4.305	0.62	14.367	0.43	0.08	1.898
15	KOH	4.303	0.62	14.403	0.43	0.08	1.903
16	KOH	6.810	0.96	14.090	0.42	0.08	1.170
17	KOH	6.805	0.96	14.100	0.42	0.08	1.171
18	KOH	6.804	0.96	14.102	0.42	0.08	1.172

Table C-24 Amount of residue catalysts in biodiesel phase of basic and acid transesterification experiment

Exp.No.	Catalyst	Amount of catalyst (g)	Biodiesel phase				
			Residue catalyst		Soaps		
			Amount of residue catalyst (g)	% of residue catalyst by weight of input catalyst	Amount of soap (g)	Amount of catalyst reacted with FFA (g)	% of catalyst reacted with FFA by weight of input catalyst
19	H_2SO_4	2.502	0.49	19.663	-	-	-
20	H_2SO_4	2.513	0.49	19.538	-	-	-
21	H_2SO_4	2.515	0.49	19.522	-	-	-
22	H_2SO_4	5.057	1.05	20.722	-	-	-
23	H_2SO_4	5.021	1.05	20.870	-	-	-
24	H_2SO_4	5.043	1.05	20.821	-	-	-
25	H_2SO_4	2.511	0.49	19.592	-	-	-
26	H_2SO_4	2.516	0.49	19.553	-	-	-
27	H_2SO_4	2.506	0.49	19.631	-	-	-
28	H_2SO_4	5.032	1.07	21.321	-	-	-
29	H_2SO_4	5.053	1.07	21.232	-	-	-
30	H_2SO_4	5.043	1.07	21.133	-	-	-
31	H_2SO_4	2.515	0.48	19.132	-	-	-
32	H_2SO_4	2.508	0.48	19.147	-	-	-
33	H_2SO_4	2.511	0.48	19.124	-	-	-
34	H_2SO_4	5.045	1.04	20.603	-	-	-
35	H_2SO_4	5.073	1.04	20.490	-	-	-
36	H_2SO_4	5.105	1.04	20.403	-	-	-

Table C-25 Amount of residue catalysts in biodiesel phase of basic and acid transesterification experiment

Exp.No.	Catalyst	Amount of catalyst (g)	Biodiesel phase				
			Residue catalyst		Soaps		
			Amount of residue catalyst (g)	% of residue catalyst by weight of input catalyst	Amount of soap (g)	Amount of catalyst reacted with FFA (g)	% of catalyst reacted with FFA by weight of input catalyst
37	NaOH	1.790	0.34	19.120	0.28	0.04	2.246
38	NaOH	1.751	0.34	19.262	0.28	0.04	2.296
39	NaOH	1.765	0.34	19.071	0.28	0.04	2.273
40	$NaOCH_3$	2.514	0.36	14.263	0.28	0.05	2.168
41	$NaOCH_3$	2.543	0.36	14.100	0.28	0.05	2.143
42	$NaOCH_3$	2.525	0.36	14.200	0.28	0.05	2.158
43	$NaOCH_3$	5.018	0.78	15.621	0.28	0.05	1.094
44	$NaOCH_3$	5.006	0.78	15.659	0.28	0.05	1.097
45	$NaOCH_3$	5.021	0.78	15.612	0.28	0.05	1.094

VITA

Mr.Narawut Thongphoem was born on September 22, 1979 in Nakhornsawan, Thailand. He received the Bachelor degree of chemical engineering from Faculty of Engineering, Mahanakorn University of Technology in April 2004. The last education is studying in Master Degree in Chemical Engineering, Chulalongkorn University that began in 2004