REFERENCES

Alonso, D.M., Mariscal, R., MorenoTost, R., Poves, M.D., and Granados, M.L. (2007) Potassium leaching during triglyceride transesterification using K/c-Al2O3 catalysts. Catalysis Communications, 8, 2074–2080.

Antolin, G. (2002) Optimization of biodiesel production by sunflower oil transesterification. Bioresource Technology, 83, 111-114.

Arzamendi, G., Campo, I., Argui˜narena, E., S´anchez, M., Montes, M., and Gand, L.M. (2007) Synthesis of biodiesel with heterogeneous NaOH/alumina catalysts: Comparison with homogeneous NaOH. Chemical Engineering Journal, 134, 123–130.

Di Serio , M., Tesser, R., Dimiccoli, M., Cammarota, F., Nastasi, M., E., and Santacesaria, E. (2006) Synthesis of biodiesel via homogeneous Lewis acid catalyst. Journal of Molecular Catalysis A: Chemical, 239, 111–115.

Ebiura, T., Echizen, T., Ishikawa, A., Murai, K., and Baba, T. (2005) Selective transesterification of triolein with methanol to methyl oleate and glycerol using alumina loaded with alkali metal salt as a solid-base catalyst. Applied CatalysisA, 283, 111-116.

Hernandez, F.J., Rıos, A.P., Gomez, D., Rubio, M., and Vıllora, G. (2006) A new recirculating enzymatic membrane reactor for ester synthesis in ionic liquid/supercritical carbon dioxide biphasic systems. Applied Catalysis B: Environmental, 67, 121–126.

Fangrui, M. and Hanna, M. (1999) Biodiesel production: a review. Bioresource Technology, 70, 1-15.

Fernandes, M., Saad, E., Meira, J., Ramos L., Mitchell, D., and Krieger, N. (2007) Esterification and transesterification reactions catalysed by addition of fermented solid to organic reaction media. Journal of Molecular Catalysis, 44, 8-13.

Freedman, B. and Schwab, A. W. (1984) Preparation and properties of diesel fuels from vegetable oils. Fuel, 66, 1372-1378.

Karmee, S. and Chadha, A. (2005) Preparation of biodiesel from crude oil of Pongamia pinnata. Bioresource Technology, 96, 1425-1429.

Kim, H.J., Kang, B.S., Kim, M.J., Park, Y.M., Kim, D.K., Lee, J.S., and Lee K.Y. (2004) Transesterification of vegetable oil to biodiesel using heterogeneous base catalyst. Catalysis Today, 93–95, 315–320.

Kusdiana, D. and Saka, S. (2001) Kinetics of transesterification in rapeseed oil to biodiesel fuel as treated in supercritical methanol. Fuel, 80, 693-698.

López, D.E., Suwannakarn, K., Bruce, D.A., and Goodwin Jr., and G.J. (2007). Esterification and transesterification on tungstated zirconia: Effect of calcination temperature. Journal of Catalysis, 247, 43–50.

Madras, G., Kolluru, C., and Kumar, R. (2004) Synthesis of biodiesel in supercritical fluids. Fuel, 83, 2029-2033.

Martın, E. and Otero, C. (2008) Different enzyme requirements for the synthesis of biodiesel:Novozym 435 and Lipozyme TL IM. Bioresource Technology, 99, 277-286

Meher, L.C., Sagar, D., and Naik, S.N. (2006) Technical aspects of biodiesel production by transesterification: a review. Renewable and Sustainable Energy Reviews, 10, 248–268.

Noiroj, K. (2006) A comparative study of and catalyst for biodiesel production via transesterification from palm oil. M.S. Thesis, The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok, Thailand.

Peterson, G.R. and Scarrah, W.P. (1984) Rapseed oil transesterification by heterogeneous catalysis. American Oil Chemist Society, 10, 1593-1597.

Rathore, V. and Madras, G. (2007) Synthesis of biodiesel from edible and non-edible oils in supercritical alcohols and enzymatic synthesis in supercritical carbon dioxide. Fuel, 86, 2650–2659.

Salis, A., Pinna, M., Monduzzi, M., and Solinas V. (2005) Biodiesel production from triolein and short chain alcohols through biocatalysis. Journal of Biotechnology, 119, 291–299.

Schuchardt, U., Serchelia, R., and Vargas R.M. (1998) Transesterification of Vegetable Oils: a Review. Journal of Brazilian Chemical Society, 9, 199-210.

Shu, Q., Yang, B., Yuan, H., Qing, S., and Zhu, G. (2007) Synthesis of biodiesel from soybean oil and methanol catalyzed by zeolite beta modified with La_3^+. Catalysis Communications, 8, 2159–2165.

Srivastava, A. and Prasad, R. (2000) Triglycerides-based diesel fuels. Renewable and Sustainable Energy Reviews, 4, 111-133.

Suppes, G.J., Dasari, M.A., Doskocil, E.J., Mankidy, P.J., and Goff, M.J. (2003) Transesterification of soybean oil with zeolite and metal catalysts. Applied Catalysis A: General, 257, 213–223.

Vicente, G., Mart, M., and Aracil, J. (2003) Integrated biodiesel production: a comparison of different homogeneous catalysts systems. Bioresource Technology, 92, 297–305.

Watanabe, Y., Pinsirodom, P., Nagao, T., Yamauchi, A., Kobayashi, T., Nishida, Y., Takagi, Y., and Shimada, Y. (2006) Conversion of acid oil by-produced in vegetable oil refining to biodiesel fuel by immobilized *Candida antarctica* lipase. Journal of Molecular Catalysis B:Enzymatic, 44, 99–105.

Wang, J.S. and Wai, C.M. (2007) Transporting metal ions using reverse micelles in alcohol modified supercritical carbon dioxide. Journal of Supercritical Fluids, 40, 176–182.

Xie, W., Peng, H., and Chen, L. (2006 a) Transesterification of soybean oil catalyzed by potassium loaded on alumina as a solid-base catalyst. Applied Catalysis A: General, 300, 67–74.

Xie, W., Peng, H., and Chen, L. (2006 b) Calcined Mg–Al hydrotalcites as solid base catalysts for methanolysis of soybean oil. Journal of Molecular Catalysis A: Chemical, 246, 24–32.

Xie, W., Huang, X., and Li, H. (2007) Soybean oil methyl esters preparation using NaX zeolites loaded with KOH as heterogeneous catalyst. Bioresource Technology, 98, 936-939.

Yang, Z. and Xie, W. (2007) Soybean oil transesterification over zinc oxide modified with alkali earth metals. Fuel Processing Technology, 88, 631–638.

Zhu, J., Chun, Y., Wang, Y., and Xu, Q. (1999) Attempts to create new shape-selective solid strong base catalysts. Catalysis Today, 51, 100-111.

Appendix A Characterization of palm oil

Table A1 Density Measurement

Property	**Palm oil**
Density at 27°C (g/ml)	0.901

Table A2 Kinematic Viscosity Measurement

Property	**Palm oil**
Kinematic Viscosity (cSt)	40.5155

Table A3 Free fatty acid Measurement

	Palm oil		
	1	2	3
Weight of Oil (g)	5.0179	5.0100	5.0023
Concentration of NaOH (N)	0.1	0.1	0.1
Volume of NaOH used (ml)	0.7	0.7	0.7
FFA (% Palmatic acid)	0.3579	0.3579	0.3579
Average FFA	0.3579		

Note: Formula

FFA (% Palmatic acid) = (56.1 x N x volume of NaOH)/(weight of sample x 2.19)

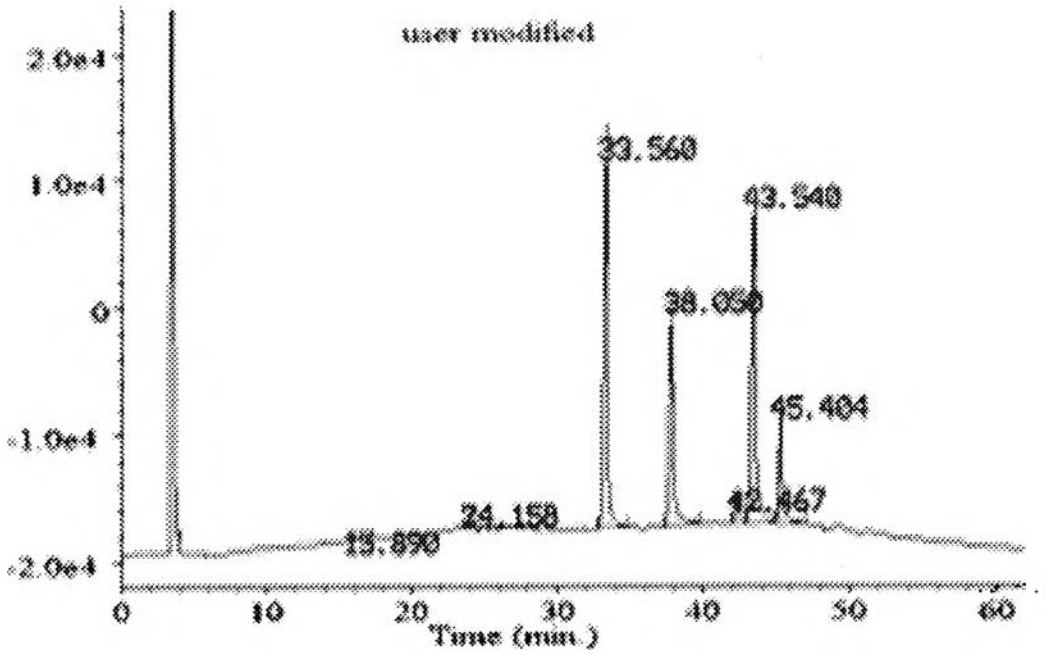
Table A4 Moisture Content Measurement

Property	**Palm oil**
Moisture Content (ppm)	452.8

Table A5 Molecular weight determination

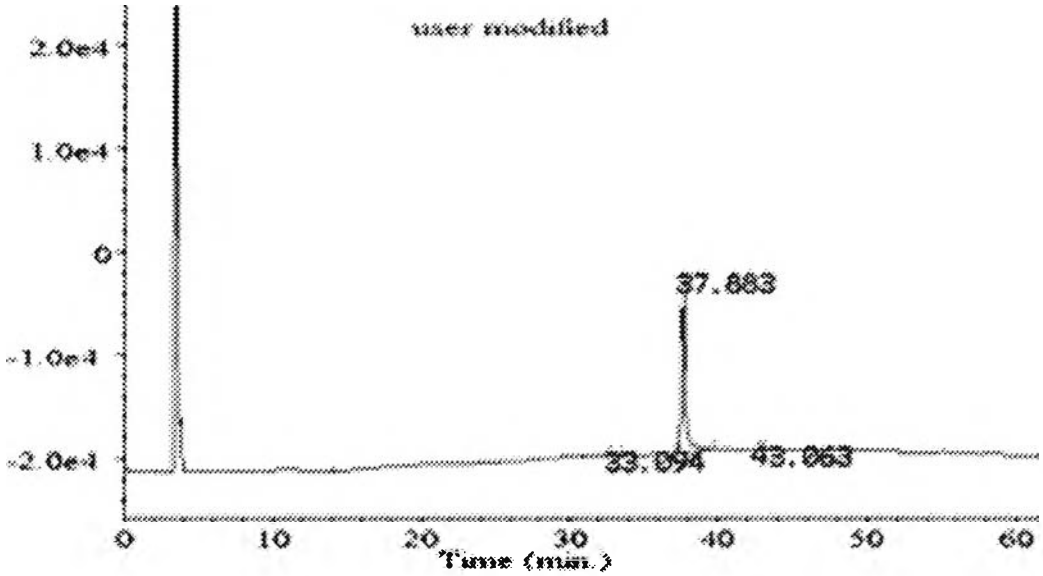
Fatty acid	**Structure**	**Molecular weight of fatty acid**	**Wt%**	**Molecular weight of fatty acid in Palm oil**
Caprylic acid	(C8:0)	158	0.0143	0.02
Capric acid	(C10:0)	186	0.0158	0.03
Lauric acid	(C12:0)	214	0.2068	0.44
Myristic acid	(C14:0)	242	0.8312	2.01
Palmitic acid	(16:0)	270	40.2992	108.81
Stearic acid	(C18:0)	298	3.7035	11.04
Oleic acid	(C18:1)	296	43.7319	129.45
Linoleic acid	(C18:2)	294	10.6456	31.30
Linolenic acid	(C18:3)	292	0.3023	0.88
Arachidic acid	(C20:0)	326	0.1991	0.65
Total	-	-	-	284.63
		3 molecle of methyl ester		853.88
		Molecular weight of Palm oil		850

Appendix B GC Chromatogram of Biodiesel



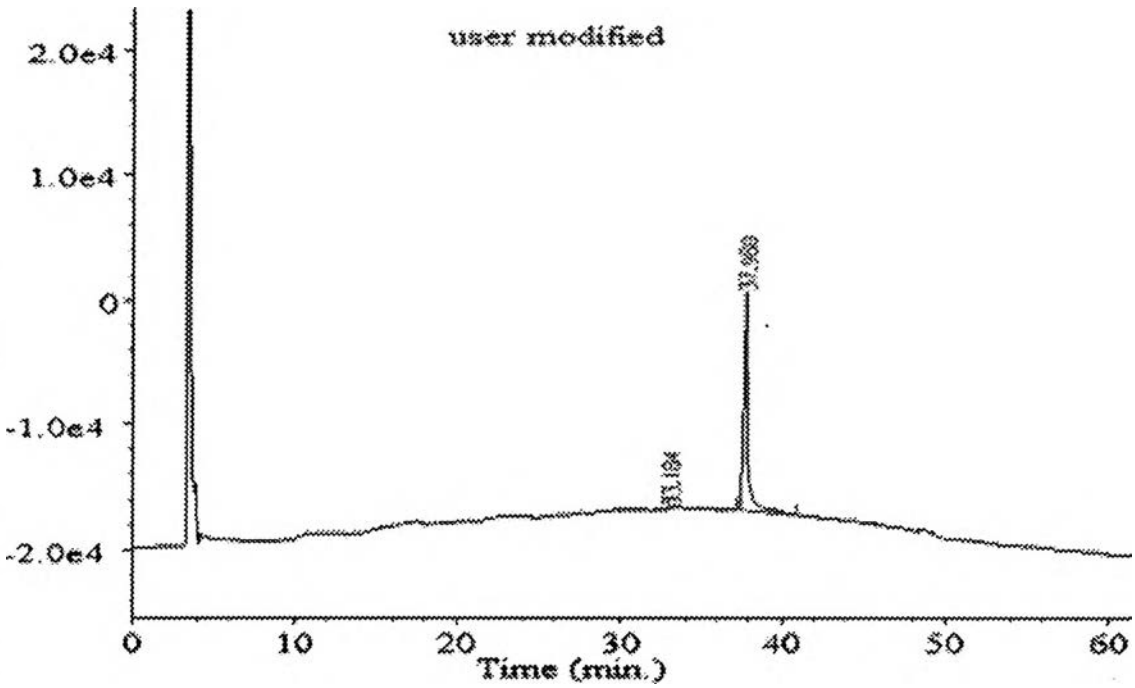
Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	15.89	MMT	0.099	3178	15.752	16.057
2	24.158	MMT	0.121	12163	24.007	24.406
3	33.56	MMT	0.257	488584	32.967	34.874
4	38.05	MMT	0.253	278908	37.427	39.87
5	42.467	MMR	0.255	39141	42.106	43.06
6	43.54	MMT	0.384	485024	43.001	44.926
7	45.404	MMT	0.23	135017	45.131	47.17

Figure B1 Methyl ester content of Biodiesel Reaction Condition: 20 wt.%K KOH/mordenite calcined 400 °C, 3 hours of reaction time, 15:1 molar ratio of methanol to oil, 3 wt.% amount of catalyst.



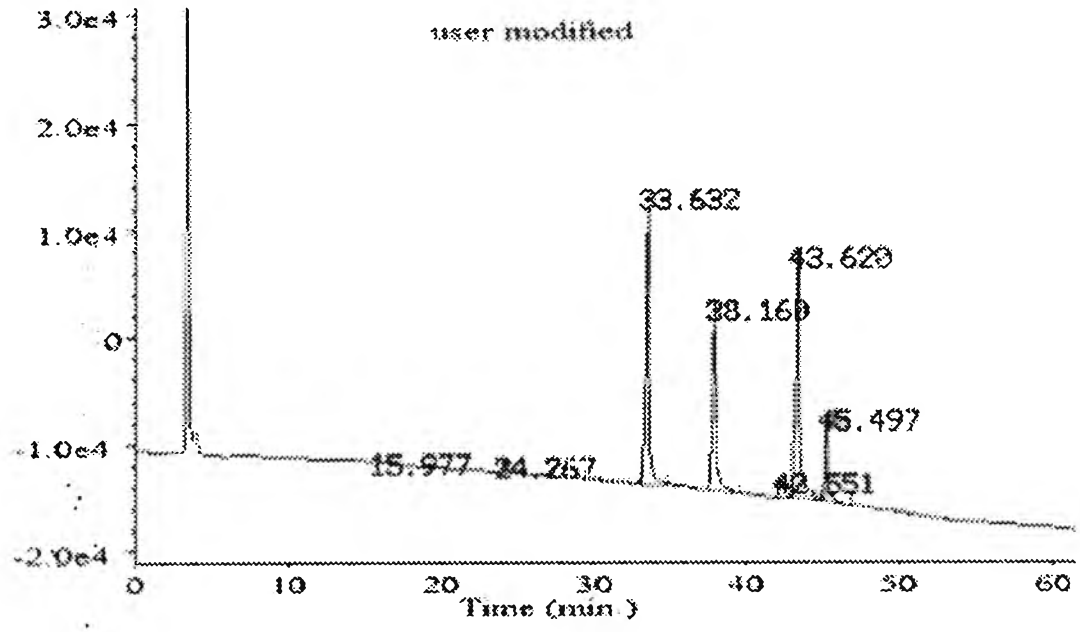
Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	33.094	MM T	0.169	2892	32.911	33.546
2	37.883	MM T	0.34	265735	37.376	39.926
3	43.063	MM T	0.178	2254	42.895	43.308

Figure B2 Methyl ester content of Biodiesel Reaction Condition: 20 wt.%K KOH/mordenite calcined 500 °C, 3 hours of reaction time, 15:1 molar ratio of methanol to oil, 3 wt.% amount of catalyst.



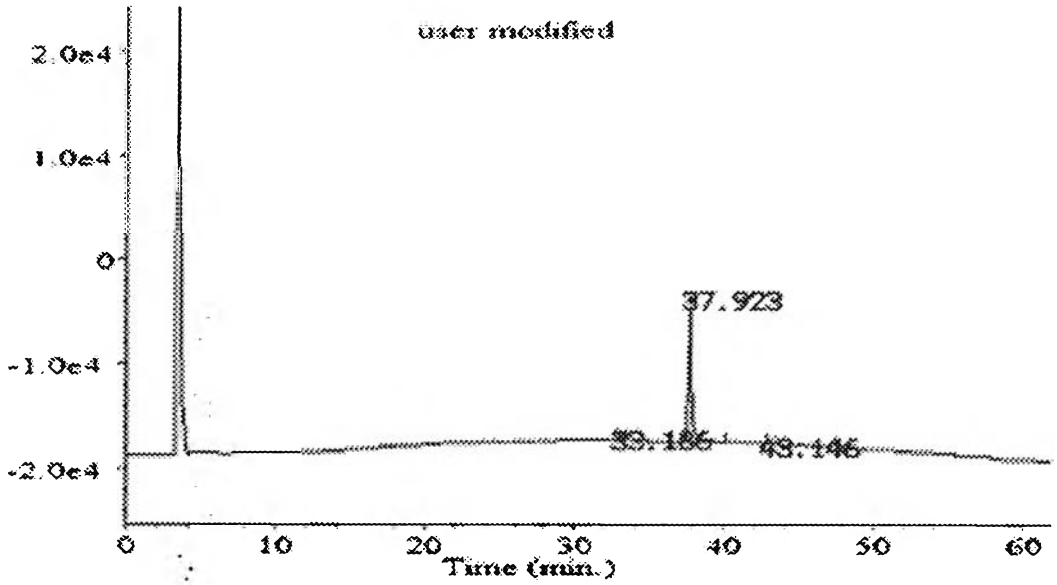
Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	33.184	MM T	0.129	1035	33.017	33.348
2	37.98	MM T	0.263	277508	37.358	40.97

Figure B3 Methyl ester content of Biodiesel Reaction Condition: 20 wt.%K KOH/mordenite calcined 600 °C, 3 hours of reaction time, 15:1 molar ratio of methanol to oil, 3 wt.% amount of catalyst.



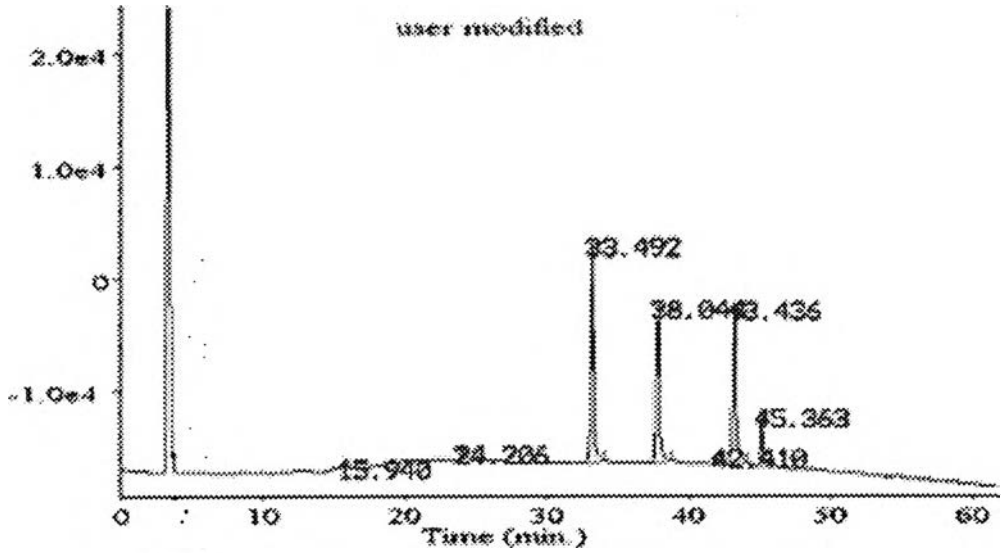
Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	15.977	MMT	0.105	3750	15.886	16.091
2	24.267	MMT	0.143	10805	24.085	24.867
3	33.632	MMT	0.247	406500	33.103	34.958
4	38.16	MMT	0.32	267941	37.714	39.693
5	42.551	MMR	0.228	29409	42.228	43.141
6	43.62	MMT	0.369	412113	43.068	45.071
7	45.497	MMT	0.219	108317	45.204	47.116

Figure B4 Methyl ester content of Biodiesel Reaction Condition: Spent^{1st} 20 wt.%K KOH/mordenite, 24 hours of reaction time, 15:1 molar ratio of methanol to oil, 3 wt.% amount of catalyst.



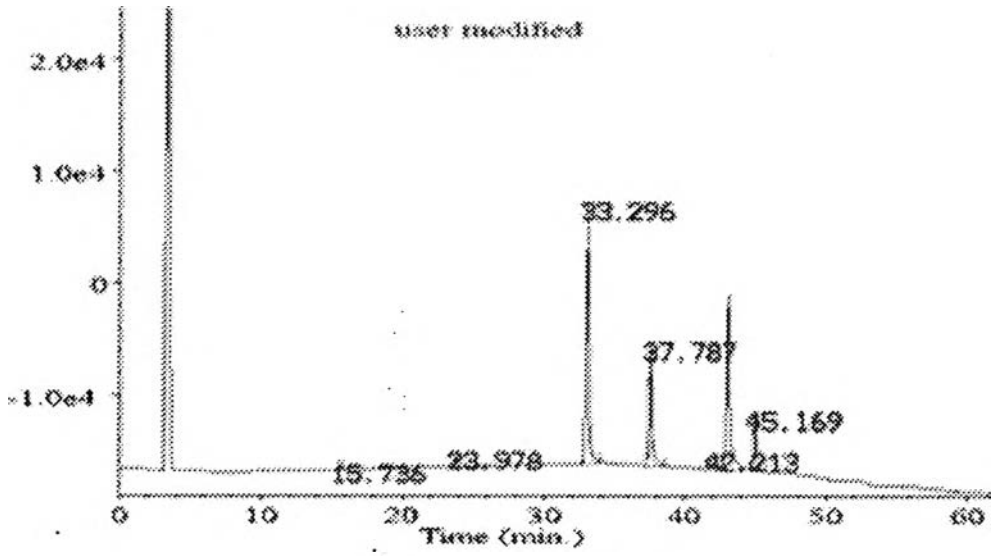
Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	33.186	MM T	0.156	6937	32.937	33.6
2	37.923	MM T	0.243	206245	37.415	40.238
3	43.146	MM T	0.206	5253	42.935	43.592

Figure B5 Methyl ester content of Biodiesel Reaction Condition: Spent[1st] 20 wt.%K KOH/ZrO_2, 24 hours of reaction time, 15:1 molar ratio of methanol to oil, 3 wt.% amount of catalyst.



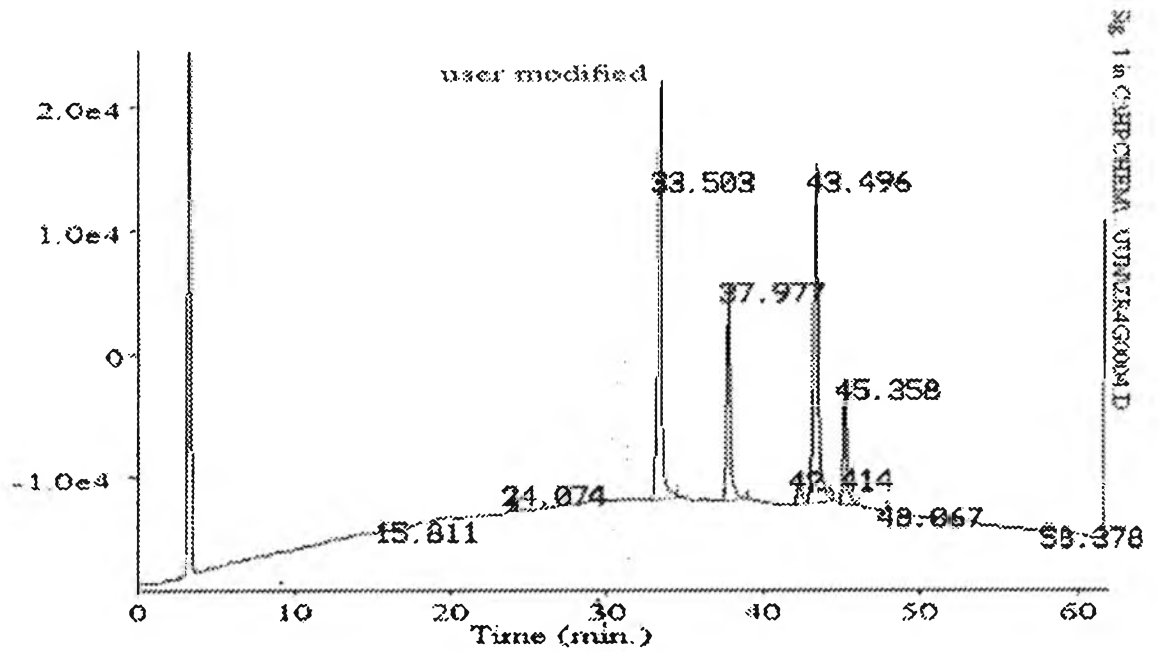
Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	15.94	MMT	0.109	2228	15.808	16.068
2	24.206	MMT	0.121	7643	24.055	24.46
3	33.492	MMT	0.206	245342	33.042	34.274
4	38.044	MMT	0.22	189645	37.657	38.93
5	42.41	MMT	0.187	13669	42.203	42.78
6	43.436	MMT	0.237	205912	43.04	44.251
7	45.363	MMT	0.188	55302	45.117	46.12

Figure B6 Methyl ester content of Biodiesel Reaction Condition: 20 wt.%K KOH/ZrO_2, 2 hours of reaction time, 15:1 molar ratio of methanol to oil, 1 wt.% amount of catalyst.



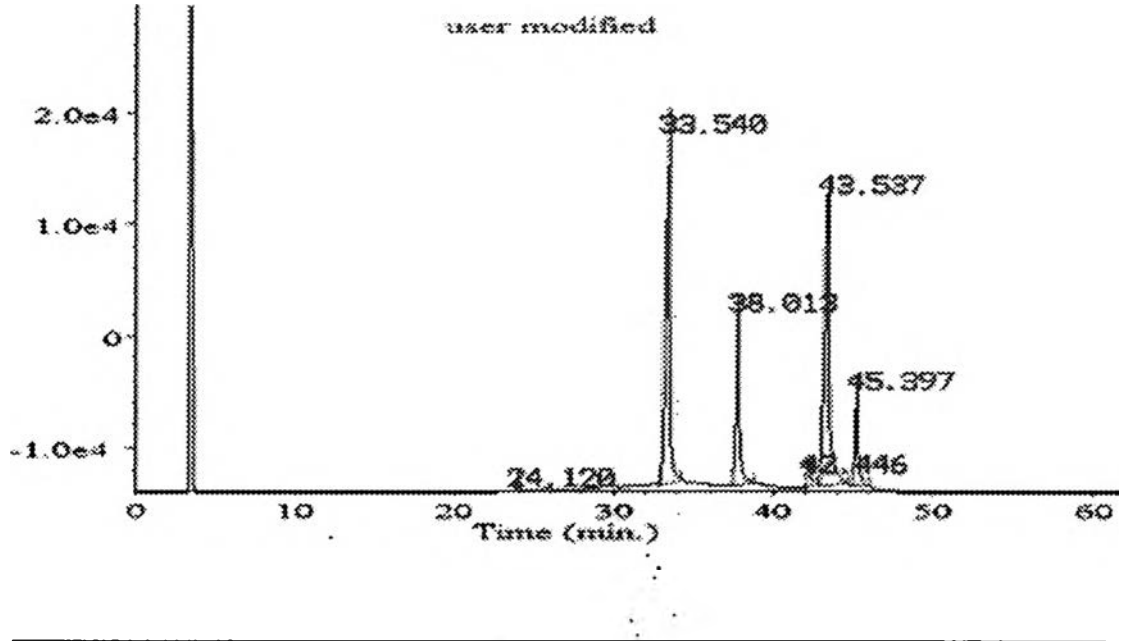
Peak	Ret Time	Type	Width	Area	Start Time	End Time
1	15.736	MM T	0.116	2650	15.562	15.989
2	23.978	MM T	0.124	7901	23.78	24.313
3	33.296	MM T	0.221	312730	32.918	34.167
4	37.787	MM T	0.212	144738	37.447	38.686
5	42.213	MM T	0.204	17557	41.974	42.728
6	43.25	MM T	0.27	252500	42.785	44.699
7	45.169	MM T	0.201	62881	44.882	46.004

Figure B7 Methyl ester content of Biodiesel 2 g. of KOH/ZrO_2 Figure B6 Methyl ester content of Biodiesel Reaction Condition: 20 wt.%K KOH/ZrO_2, 2 hours of reaction time, 15:1 molar ratio of methanol to oil, 2 wt.% amount of catalyst.



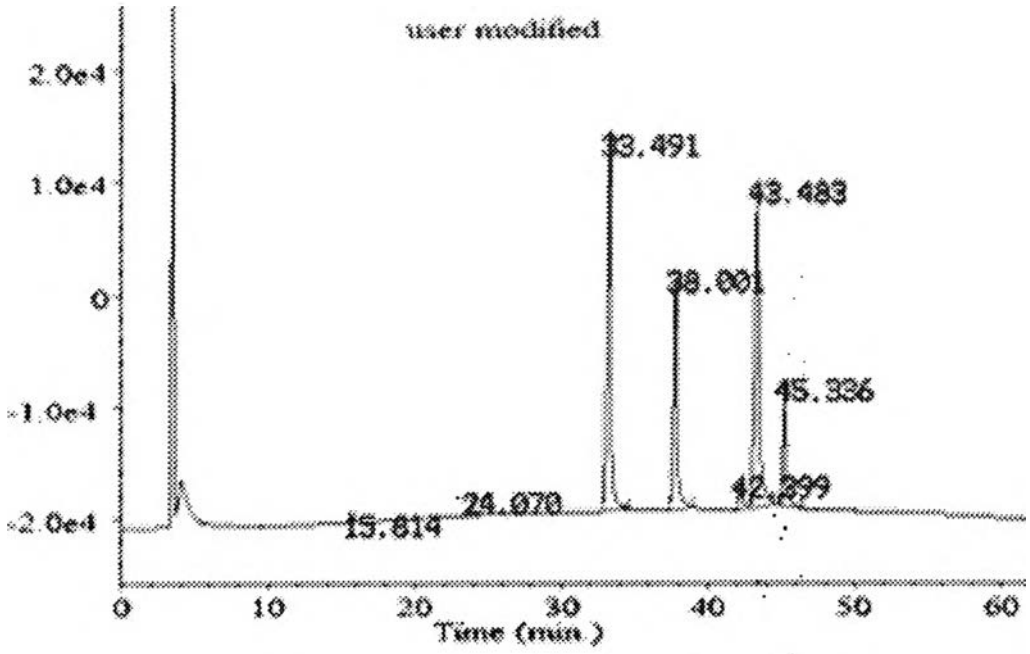
Peak#	Ret. Time	Type	Width	Area	Start Time	End Time
1	15.811	MMT	0.101	3610	15.68	15.957
2	24.074	MMT	0.118	13314	23.938	24.322
3	33.503	MMT	0.267	541259	32.98	34.604
4	37.977	MMT	0.24	250725	37.573	39.129
5	42.414	MMT	0.259	40437	42.077	42.98
6	43.496	MMT	0.307	502480	42.985	44.608
7	45.358	MMT	0.215	130030	45.038	46.184
8	48.067	MMT	0.126	1455	47.966	48.228
9	58.378	MMT	0.105	1463	58.19	58.479

Figure B8 Methyl ester content of Biodiesel Reaction Condition: 20 wt.%K KOH/ZrO_2, 2 hours of reaction time, 15:1 molar ratio of methanol to oil, 4 wt.% amount of catalyst.



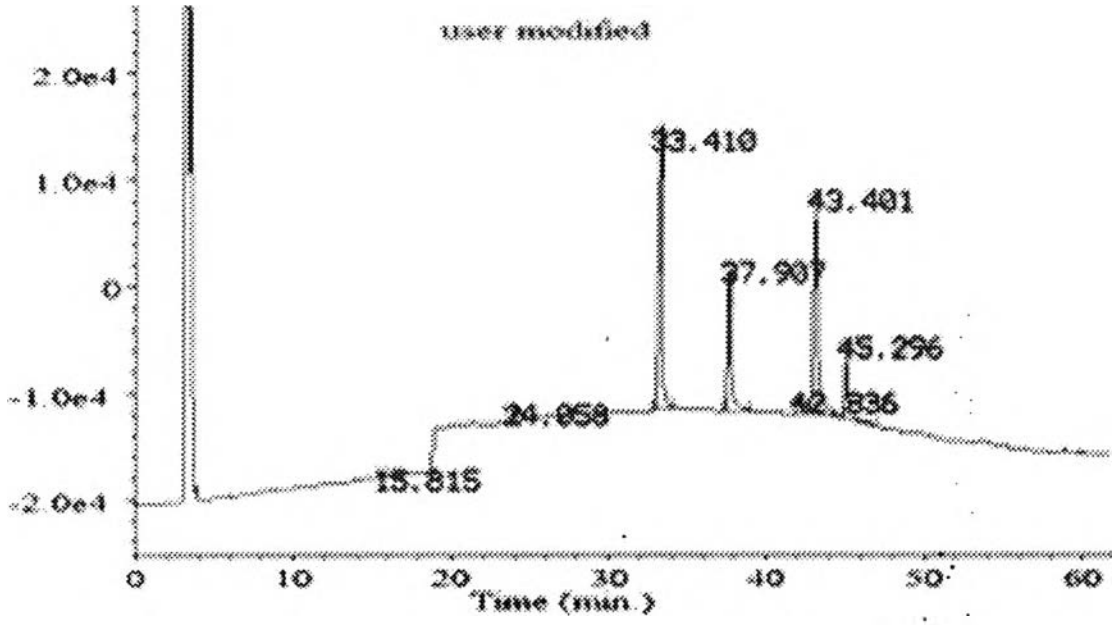
Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	15.855	MMT	0.099	3721	15.732	16.025
2	24.12	MMT	0.115	12848	23.957	24.313
3	33.54	MMT	0.256	515112	32.898	34.357
4	38.013	MMT	0.287	238850	37.627	38.945
5	42.446	MMT	0.229	35752	42.156	42.843
6	43.537	MMT	0.31	512750	43.036	44.834
7	45.397	MMT	0.204	123736	45.143	46.129

Figure B9 Methyl ester content of Biodiesel Reaction Condition: 20 wt.%K KOH/ZrO_2, 2 hours of reaction time, 15:1 molar ratio of methanol to oil, 5 wt.% amount of catalyst.



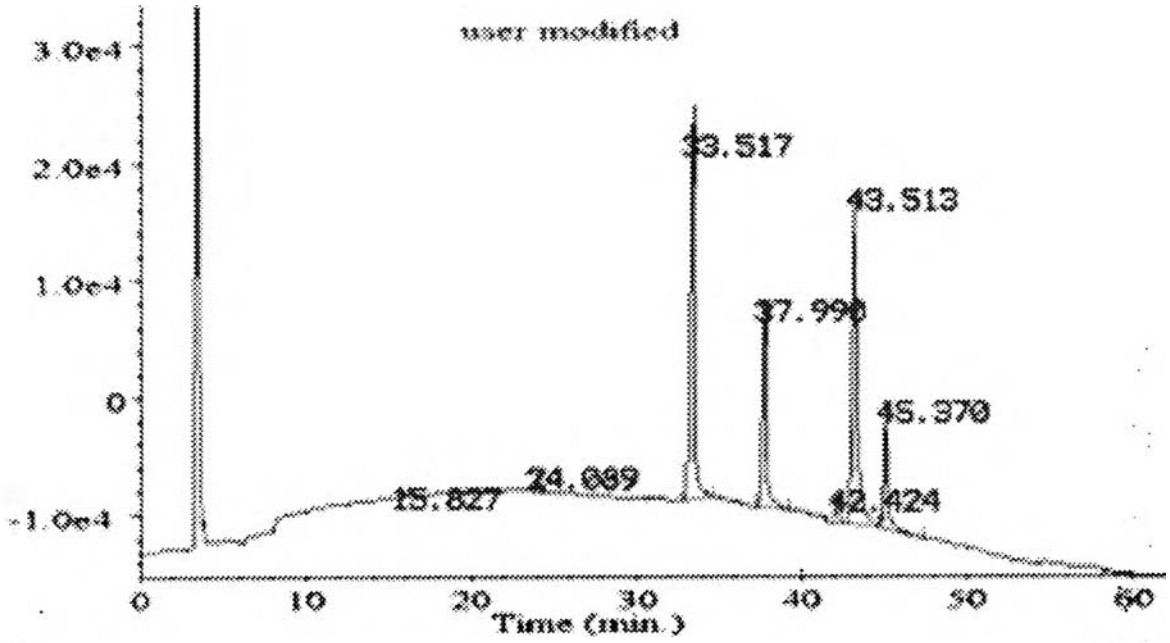
Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	15.814	MMT	0.099	3223	15.612	16.093
2	24.07	MMT	0.127	13679	23.829	24.567
3	33.491	MMT	0.267	542753	32.889	34.808
4	38.001	MMT	0.257	328137	37.53	39.114
5	42.399	MMR	0.25	40247	42.077	42.959
6	43.483	MMT	0.317	549674	42.922	44.649
7	45.336	MMT	0.22	147629	45.034	46.538

Figure B10 Methyl ester content of Biodiesel Reaction Condition: 20 wt.%K KOH/mordenite, 3 hours of reaction time, 15:1 molar ratio of methanol to oil, 1 wt.% amount of catalyst.



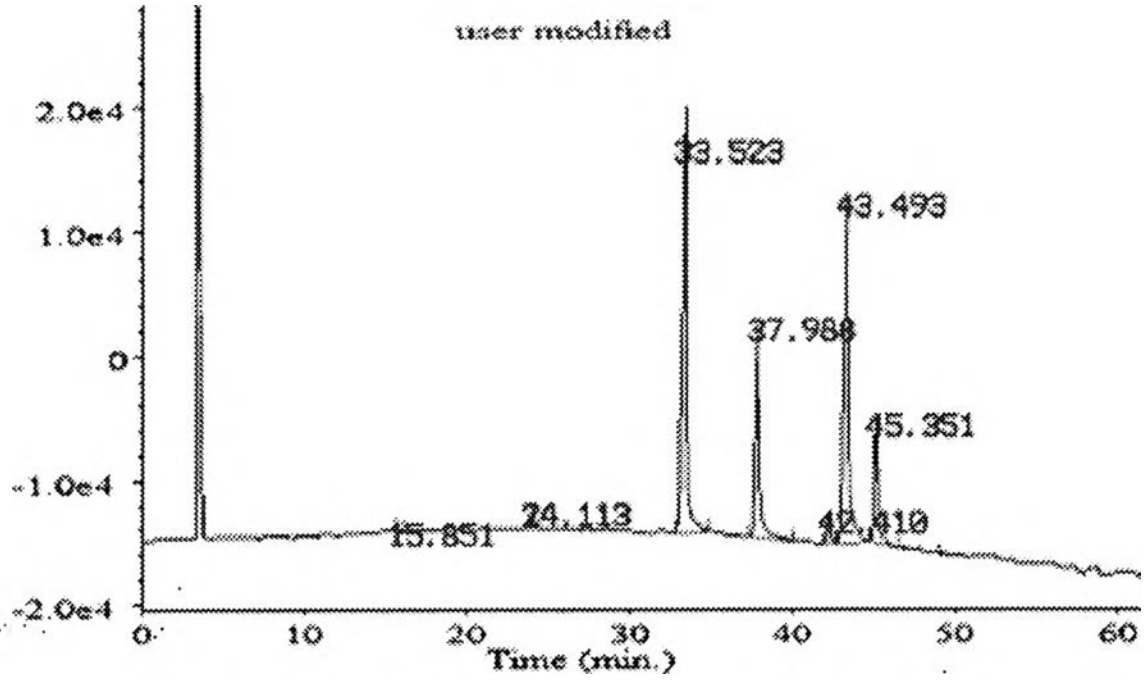
Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	15.815	MMT	0.147	4106	15.46	16.063
2	24.058	MMT	0.146	12324	23.802	24.486
3	33.41	MMT	0.325	374794	32.903	34.244
4	37.907	MMT	0.226	186712	37.401	39.031
5	42.336	MMR	0.237	27673	42.083	42.966
6	43.401	MMT	0.293	370074	42.843	44.879
7	45.296	MMT	0.227	103313	45.04	47.111

Figure B11 Methyl ester content of Biodiesel Reaction Condition: 20 wt.%K KOH/mordenite, 3 hours of reaction time, 15:1 molar ratio of methanol to oil, 2 wt.% amount of catalyst.



Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	15.827	MMT	0.131	3906	15.653	16.211
2	24.089	MMT	0.128	14488	23.86	24.476
3	33.517	MMT	0.277	558668	32:838	34.839
4	37.99	MMT	0.358	263778	37.397	39.28
5	42.424	MMT	0.241	38684	42.099	42.955
6	43.513	MMR	0.318	543082	42.96	44.823
7	45.37	MMT	0.239	154540	45.029	47.558

Figure B12 Methyl ester content of Biodiesel Reaction Condition: 20 wt.%K KOH/mordenite, 3 hours of reaction time, 15:1 molar ratio of methanol to oil, 4 wt.% amount of catalyst.



Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	15.851	MMT	0.115	4177	15.733	16.139
2	24.113	MMT	0.127	14257	23.888	24.526
3	33.523	MMT	0.392	571070	32.89	34.999
4	37.988	MMT	0.258	271517	37.409	40.123
5	42.41	MMR	0.254	39053	42.009	42.974
6	43.493	MMT	0.409	532525	42.9	44.921
7	45.351	MMT	0.226	138666	45.039	46.671

Figure B13 Methyl ester content of Biodiesel Reaction Condition: 20 wt.%K KOH/mordenite, 3 hours of reaction time, 15:1 molar ratio of methanol to oil, 5 wt.% amount of catalyst.

CURRICULUM VITAE

Name: Ms. Sotsanan Iangthanarat

Date of Birth: July 20, 1984

Nationality: Thai

University Education:

2002-2006 Bachelor Degree of Chemical Engineering, Faculty of Engineering, Mahidol University, Bangkok, Thailand

Proceeding:

1. Iangthanarat, S., Luengnaruemitchai, A., and Jai-In, S. (2008, April 23) Transesterification of palm oil using KOH/ZrO_2 and KOH/mordenite as a heterogeneous catalyst. Proceeding of 14th PPC Symposium on Petroleum, Petrochemical, and Polymers, Bangkok, Thailand.

Presentation:

1. Iangthanarat, S., Luengnaruemitchai, A., and Jai-In, S. (2007, October 29-30) Transesterification of palm oil using KOH/ZrO_2 and KOH/mordenite as a heterogeneous catalyst. Oral presented at 17th Thailand Chemical Engineering and Applied Chemistry 2007, Chiangmai, Thailand.
2. Iangthanarat, S., Luengnaruemitchai, A., and Jai-In, S. (2008, April 23) Transesterification of palm oil using KOH/ZrO_2 and KOH/mordenite as a heterogeneous catalyst. Poster presented at 14th PPC Symposium on Petroleum, Petrochemical, and Polymers, Bangkok, Thailand.