APPENDIX A

CALCULATION OF THE MOLECULAR WEIGHT OF MCPO

Main fatty acid of MCPO (Table 2.2)

Palmitic acid = 47 %wt Oleic acid = 43 %wt Linoleic acid = 10 %wt

Calculation of molecular weight of TG

Molecular weight of TG (Palmitic acid) = 806 g/mol
Molecular weight of TG (Oleic acid) = 884 g/mol
Molecular weight of TG (Linoleic acid) = 878 g/mol

Average of molecular weight of TG = (806 x 0.47) + (884 x 0.43) + (878 x 0.10)
= 846.64 g/mol

Calculation of molecular weight of DG

Molecular weight of DG (Palmitic acid) = 568 g/mol
Molecular weight of DG (Oleic acid) = 620 g/mol
Molecular weight of DG (Linoleic acid) = 616 g/mol

Average of molecular weight of DG = (568 x 0.47) + (620 x 0.43) + (616 x 0.10)
= 595.16 g/mol

Calculation of molecular weight of MG

Molecular weight of MG (Palmitic acid) = 318 g/mol
Molecular weight of MG (Oleic acid) = 356 g/mol
Molecular weight of MG (Linoleic acid) = 354 g/mol

Average of molecular weight of MG = (318 x 0.47) + (356 x 0.43) + (354 x 0.10)
= 338.04 g/mol

Calculation of molecular weight of FFA

Molecular weight of FFA (Palmitic acid) = 256 g/mol
Molecular weight of FFA (Oleic acid) = 282 g/mol
Molecular weight of FFA (Linoleic acid) = 280 g/mol

Average of molecular weight of FFA = (256 x 0.47) + (282 x 0.43) + (280 x 0.10)
= 269.58 g/mol

Calculation of molecular weight of ME

Molecular weight of ME (Palmitic acid) = 270 g/mol
Molecular weight of ME (Oleic acid) = 296 g/mol
Molecular weight of ME (Linoleic acid) = 294 g/mol

Average of molecular weight of ME = (270 x 0.47) + (296 x 0.43) + (294 x 0.10)
= 283.58 g/mol

Table A.1 The concentration of compounds in MCPO from analysis using standard methods

Analytic Method	**The concentration of compounds in MCPO (%wt)**				
	TG	**DG**	**MG**	**FFA**	**ME**
Standard Method*	82.068	8.823	0.204	8.632	0.274

*Source from Figure E.2, E.3, and E.4

Calculation of molecular weight of MCPO by Standard Method

Molecular weight of MCPO = (846.64 x 0.821) + (595.16 x 0.088) +
(338.04 x 0.002) + (269.58 x 0.086) +
(283.58 x 0.003)
= 772.065 g/mol #

APPENDIX B

KARL FISCHER ANALYSIS

Karl Fisher

The first-stage samples were analyzed for water by Karl Fisher. The weighed commercial methanol was added in the weighed samples and shaken. Then the solutions were released for separating the oily solution and clear solution. After that, the clear solution, which was drawn and weighed, was analyzed for the amount of water with Karl Fisher. The mass ratio of water was determined and then calculated the real mass ratio of water in each sample.

Example: What is the concentration of water in CPO (0.500 g) when 0.529 %wt is the concentration of water in the clear solution (MeOH) (2.420g) with 0.100 %wt water?

Solve:

Clear solution	100	g has water (solution + MeOH)		0.529	g
Clear solution	2.420	g has water		0.0128	g
MeOH	100	g has water		0.100	g
MeOH	2.420	g has water		0.00242	g

$\therefore$ Clear solution has water 0.0128-0.00242 = 0.01038 g

Sampling	0.500	g has water		0.01038	g
Sampling	100	g has water		2.0760	g

APPENDIX C

COMPARISON OF ANALYTICAL INSTRUMENT

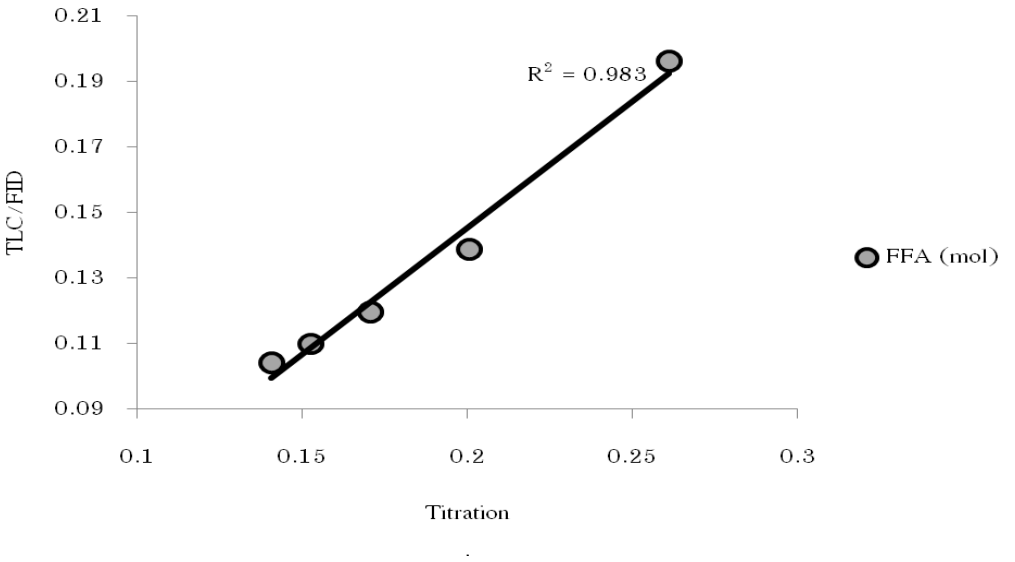


Figure C.1 Comparison of FFA determination between TLC/FID and Titration

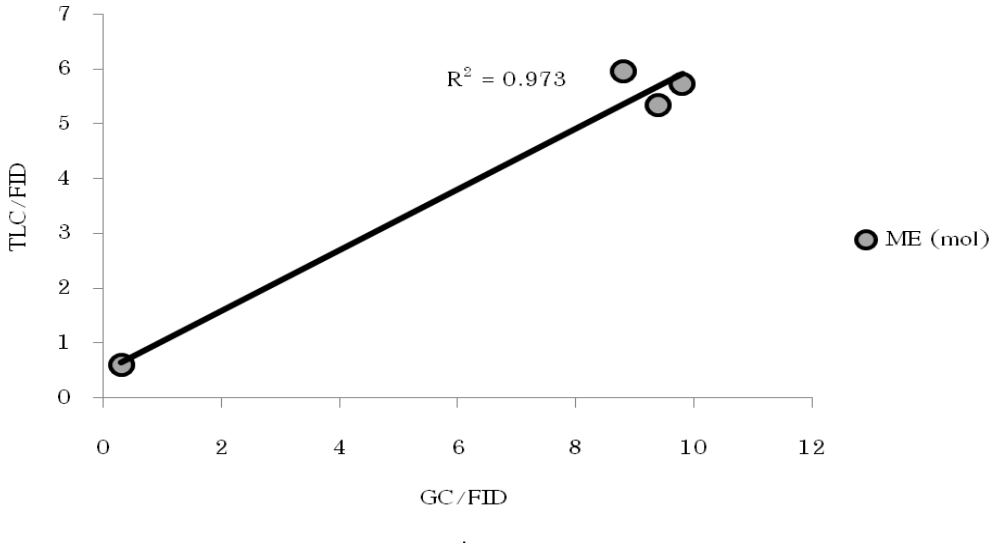
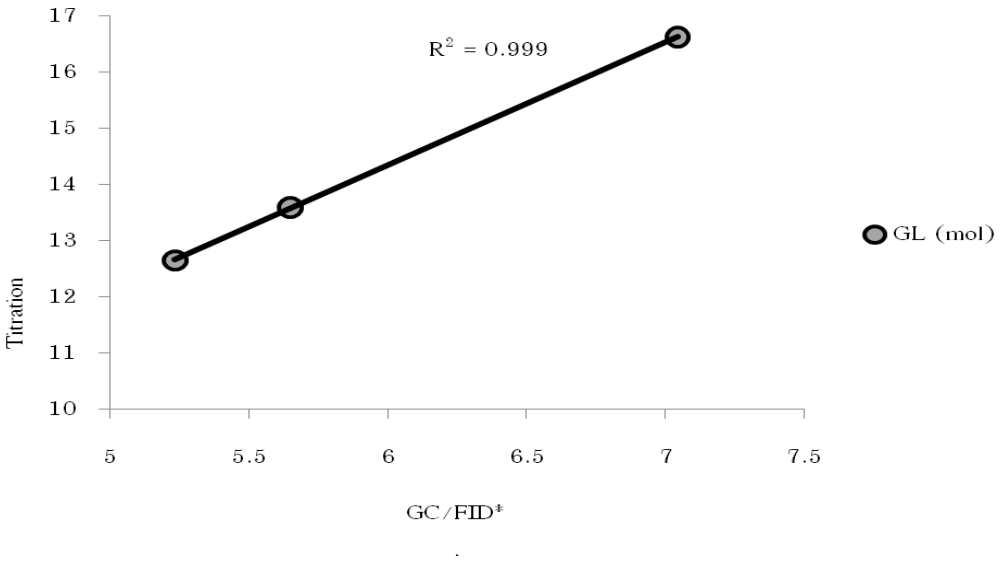


Figure C.2 Comparison of ME determination between TLC/FID and GC/FID



*GL data from GC/FID tried out by analyst from Science Equipment Center, PSU

Figure C.3 Comparison of GL determination between Titration and GC/FID

APPENDIX D

RAW DATA FOR THE TWO-STAGE PROCESS

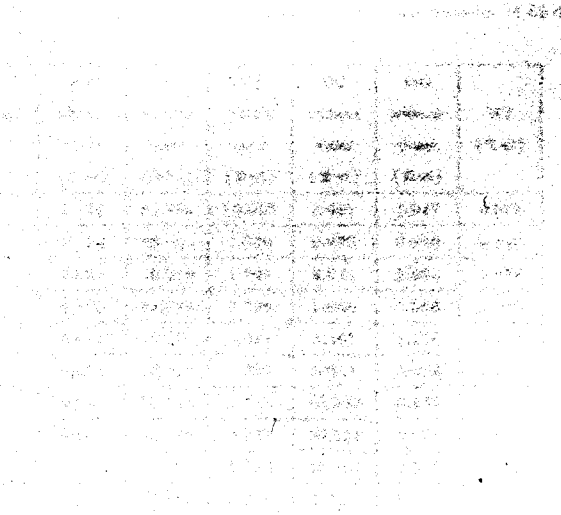


Table D.1 FFA conversion in MCPO by using a 1:1 molar ratio of methanol to oil at a temperature of 55 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without water (%wt)	TG without water (%wt)	FFA without water (%wt)	DG without water (%wt)	MG without water (%wt)	WT (%wt)
0	1.832	2	1.584	82.722	11.057	4.218	0.119	0.079
0.5	1.824	2	8.019	77.653	4.564	9.074	0.690	0.481
1	1.820	2	9.271	77.416	3.286	9.111	0.916	0.464
3	1.820	2	8.350	80.249	2.704	7.943	0.755	0.584
5	1.812	2	10.120	78.091	1.749	9.207	0.832	0.607
7	1.818	2	8.188	80.690	2.327	8.143	0.652	0.573
9	1.810	2	7.680	83.647	1.564	5.961	1.149	0.461
12	1.816	2	9.857	78.888	2.061	8.394	0.801	0.493
15	1.822	2	8.432	80.171	2.467	8.241	0.690	0.590
20	1.810	2	9.885	79.078	1.885	8.349	0.802	0.692

Table D.2 FFA conversion in MCPO by using a 1:1 molar ratio of methanol to oil at a temperature of 60 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without water (%wt)	TG without water (%wt)	FFA without water (%wt)	DG without water (%wt)	MG without water (%wt)	WT (%wt)
0	1.832	2	1.282	83.710	10.328	4.523	0.157	0.064
0.5	1.828	2	3.982	83.354	5.489	6.699	0.475	0.319
1	1.824	2	5.916	81.650	4.604	7.335	0.494	0.473
3	1.820	2	6.336	86.333	2.164	4.806	0.361	0.507
5	1.812	2	3.759	89.637	1.585	4.641	0.378	0.301
7	1.812	2	4.856	88.817	1.229	4.688	0.410	0.388
9	1.816	2	4.301	89.777	1.327	4.318	0.277	0.344
12	1.810	2	6.956	84.392	2.532	5.851	0.270	0.556
15	1.808	2	7.122	81.567	2.659	6.888	0.383	0.570
20	1.812	2	7.690	83.930	2.659	5.318	0.403	0.615

Table D.3 FFA conversion in MCPO by using a 1:1 molar ratio of methanol to oil at a temperature of 65 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without water (%wt)	TG without water (%wt)	FFA without water (%wt)	DG without water (%wt)	MG without water (%wt)	WT (%wt)
0	1.832	2	1.774	83.159	10.057	4.361	1.047	0.089
0.5	1.82	2	7.718	82.583	1.900	6.990	0.810	0.540
1	1.812	2	9.687	79.619	1.601	8.071	1.024	0.678
3	1.8	2	5.178	84.936	1.599	7.686	0.603	0.362
5	1.81	2	6.674	82.275	1.685	8.255	1.110	0.467
7	1.81	2	5.865	78.316	1.669	9.757	4.394	0.411
9	1.802	2	8.235	78.959	1.193	10.133	0.481	0.576
12	1.816	2	8.746	78.026	1.218	10.134	0.978	0.612
15	1.812	2	9.846	77.318	1.228	10.991	0.618	0.689
20	1.78	2	10.612	77.726	0.973	9.731	0.958	0.743

Table D.4 FFA conversion in MCPO by using a 2.5:1 molar ratio of methanol to oil at a temperature of 55 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without water (%wt)	TG without water (%wt)	FFA without water (%wt)	DG without water (%wt)	MG without water (%wt)	WT (%wt)
0	1.832	2	0.000	86.809	11.957	4.013	0.941	0.080
0.5	1.808	2	6.508	85.316	1.381	6.200	0.597	0.390
1	1.798	2	6.646	86.332	0.945	5.853	0.525	0.332
3	1.790	2	6.483	86.208	0.881	5.995	0.633	0.454
5	1.800	2	7.061	84.103	0.905	7.590	0.342	0.424
7	1.804	2	6.704	87.089	1.169	5.088	0.551	0.469
9	1.802	2	9.540	79.984	1.308	8.321	0.848	0.572
12	1.794	2	9.427	76.373	1.204	11.424	1.174	0.471
15	1.798	2	8.629	83.985	1.317	6.459	0.600	0.604
20	1.788	2	6.970	84.850	1.117	6.548	0.515	0.488

Table D.5 FFA conversion in MCPO by using a 2.5:1 molar ratio of methanol to oil at a temperature of 60 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without water (%wt)	TG without water (%wt)	FFA without water (%wt)	DG without water (%wt)	MG without water (%wt)	WT (%wt)
0	1.832	2	1.564	83.290	10.559	4.585	0.541	0.098
0.5	1.788	2	8.438	83.223	0.828	6.413	1.698	0.422
1	1.794	2	7.793	85.696	0.687	5.633	0.192	0.468
3	1.802	2	9.426	85.400	0.864	6.784	0.427	0.613
5	1.782	2	9.940	79.539	0.526	9.555	0.541	0.646
7	1.792	2	10.850	77.700	0.470	8.615	1.368	0.543
9	1.794	2	10.335	77.216	0.637	9.407	0.506	0.517
12	1.790	2	10.718	77.167	0.415	10.173	0.529	0.643
15	1.786	2	10.286	76.854	0.551	10.417	0.493	0.514
20	1.784	2	12.316	75.509	0.817	10.986	0.374	0.616

Table D.6 FFA conversion in MCPO by using a 2.5:1 molar ratio of methanol to oil at a temperature of 65 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without water (%wt)	TG without water (%wt)	FFA without water (%wt)	DG without water (%wt)	MG without water (%wt)	WT (%wt)
0	1.832	2	1.473	84.891	11.559	4.065	1.069	0.074
0.5	1.788	2	9.298	82.887	0.677	6.295	0.844	0.465
1	1.794	2	8.576	84.886	0.449	5.660	0.430	0.515
3	1.798	2	9.851	83.541	0.671	5.222	0.716	0.542
5	1.782	2	9.844	82.076	0.531	6.830	0.521	0.541
7	1.78	2	10.366	82.903	0.118	4.282	1.333	0.570
9	1.794	2	8.042	84.931	0.332	6.396	0.301	0.563
12	1.79	2	8.810	80.036	0.574	9.394	0.987	0.529
15	1.792	2	9.906	81.941	0.498	6.512	0.335	0.799
20	1.782	2	7.749	84.211	0.593	6.022	0.848	0.585

Table D.7 FFA conversion in MCPO by using a 3.5:1 molar ratio of methanol to oil at a temperature of 55 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without water (%wt)	TG without water (%wt)	FFA without water (%wt)	DG without water (%wt)	MG without water (%wt)	WT (%wt)
0	1.832	2	1.864	85.345	10.038	3.592	0.160	0.093
0.5	1.788	2	7.843	85.608	0.601	5.999	0.150	0.549
1	1.794	2	9.273	84.181	0.261	6.175	0.110	0.649
3	1.790	2	8.363	85.586	0.153	5.806	0.092	0.585
5	1.786	2	10.206	83.152	0.200	5.683	0.161	0.714
7	1.786	2	9.161	83.856	0.357	6.404	0.123	0.641
9	1.784	2	10.683	82.435	0.211	6.616	0.057	0.748
12	1.794	2	10.074	84.251	0.256	5.319	0.099	0.705
15	1.796	2	10.395	84.272	0.221	5.077	0.106	0.728
20	1.784	2	7.949	86.632	0.080	5.250	0.089	0.556

Table D.8 FFA conversion in MCPO by using a 3.5:1 molar ratio of methanol to oil at a temperature of 60 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without water (%wt)	TG without water (%wt)	FFA without water (%wt)	DG without water (%wt)	MG without water (%wt)	WT (%wt)
0	1.832	2	1.864	83.290	9.820	4.585	0.441	0.098
0.5	1.780	2	8.642	82.320	0.283	8.416	0.349	0.588
1	1.782	2	10.985	82.797	0.130	4.817	0.272	0.604
3	1.780	2	9.388	85.120	0.130	4.504	0.860	0.610
5	1.788	2	10.145	83.078	0.053	6.530	0.195	0.710
7	1.782	2	7.349	88.660	0.000	3.549	0.444	0.514
9	1.786	2	9.436	84.419	0.131	6.336	0.180	0.613
12	1.780	2	8.994	80.634	0.080	9.387	0.208	0.630
15	1.790	2	9.318	84.255	0.091	4.779	0.763	0.606
20	1.784	2	9.318	84.804	0.000	5.281	0.598	0.652

Table D.9 FFA conversion in MCPO by using a 3.5:1 molar ratio of methanol to oil at a temperature of 65 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without water (%wt)	TG without water (%wt)	FFA without water (%wt)	DG without water (%wt)	MG without water (%wt)	WT (%wt)
0	1.832	2	1.133	84.530	9.627	4.584	0.279	0.057
0.5	1.782	2	9.089	83.520	0.923	6.226	1.166	0.591
1	1.784	2	7.558	84.513	0.295	6.137	1.499	0.605
3	1.780	2	7.647	85.453	0.125	5.990	0.786	0.612
5	1.786	2	9.584	88.982	0.135	5.753	0.546	0.719
7	1.782	2	8.714	82.233	0.302	7.986	0.566	0.654
9	1.780	2	10.239	81.140	0.294	7.712	0.616	0.717
12	1.780	2	9.300	81.498	0.141	8.394	0.269	0.698
15	1.782	2	9.188	78.930	0.223	10.454	0.392	0.735
20	1.786	2	7.690	80.359	0.923	8.297	0.993	0.754

Table D.10 ME conversion in MCPO by using a 2.5:1 molar ratio of methanol to oil at a temperature of 55 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without GL (%wt)	TG without GL (%wt)	DG without GL (%wt)	MG without GL (%wt)	GL (%wt)
0	1.832	2	1.282	7.957	4.623	0.157	0.064
0.5	1.828	2	3.982	83.354	6.699	0.475	0.319
1	1.824	2	5.916	81.650	7.335	0.494	0.473
3	1.820	2	6.336	86.333	4.806	0.361	0.507
5	1.812	2	3.759	89.637	4.641	0.378	0.301
7	1.812	2	4.856	88.817	4.688	0.410	0.388
9	1.816	2	4.301	89.777	4.318	0.277	0.344
12	1.810	2	6.956	84.392	5.851	0.270	0.556
15	1.808	2	7.122	81.567	6.888	0.383	0.570
20	1.812	2	7.690	83.930	5.318	0.403	0.615

Table D.11 ME conversion in MCPO by using a 2.5:1 molar ratio of methanol to oil at a temperature of 60 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without GL (%wt)	TG without GL (%wt)	DG without GL (%wt)	MG without GL (%wt)	GL (%wt)
0	1.832	2	1.282	7.957	4.623	0.157	0.064
0.5	1.828	2	3.982	83.354	6.699	0.475	0.319
1	1.824	2	5.916	81.650	7.335	0.494	0.473
3	1.820	2	6.336	86.333	4.806	0.361	0.507
5	1.812	2	3.759	89.637	4.641	0.378	0.301
7	1.812	2	4.856	88.817	4.688	0.410	0.388
9	1.816	2	4.301	89.777	4.318	0.277	0.344
12	1.810	2	6.956	84.392	5.851	0.270	0.556
15	1.808	2	7.122	81.567	6.888	0.383	0.570
20	1.812	2	7.690	83.930	5.318	0.403	0.615

Table D.12 ME conversion in MCPO by using a 2.5:1 molar ratio of methanol to oil at a temperature of 65 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without GL (%wt)	TG without GL (%wt)	DG without GL (%wt)	MG without GL (%wt)	GL (%wt)
0	1.832	2	1.282	7.957	4.623	0.157	0.064
0.5	1.828	2	3.982	83.354	6.699	0.475	0.319
1	1.824	2	5.916	81.650	7.335	0.494	0.473
3	1.820	2	6.336	86.333	4.806	0.361	0.507
5	1.812	2	3.759	89.637	4.641	0.378	0.301
7	1.812	2	4.856	88.817	4.688	0.410	0.388
9	1.816	2	4.301	89.777	4.318	0.277	0.344
12	1.810	2	6.956	84.392	5.851	0.270	0.556
15	1.808	2	7.122	81.567	6.888	0.383	0.570
20	1.812	2	7.690	83.930	5.318	0.403	0.615

Table D.13 ME conversion in MCPO by using a 5:1 molar ratio of methanol to oil at a temperature of 55 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without GL (%wt)	TG without GL (%wt)	DG without GL (%wt)	MG without GL (%wt)	GL (%wt)
0	1.832	2	1.282	7.957	4.623	0.157	0.064
0.5	1.828	2	3.982	83.354	6.699	0.475	0.319
1	1.824	2	5.916	81.650	7.335	0.494	0.473
3	1.820	2	6.336	86.333	4.806	0.361	0.507
5	1.812	2	3.759	89.637	4.641	0.378	0.301
7	1.812	2	4.856	88.817	4.688	0.410	0.388
9	1.816	2	4.301	89.777	4.318	0.277	0.344
12	1.810	2	6.956	84.392	5.851	0.270	0.556
15	1.808	2	7.122	81.567	6.888	0.383	0.570
20	1.812	2	7.690	83.930	5.318	0.403	0.615

Table D.14 ME conversion in MCPO by using a 5:1 molar ratio of methanol to oil at a temperature of 60 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without GL (%wt)	TG without GL (%wt)	DG without GL (%wt)	MG without GL (%wt)	GL (%wt)
0	1.832	2	1.282	7.957	4.623	0.157	0.064
0.5	1.828	2	3.982	83.354	6.699	0.475	0.319
1	1.824	2	5.916	81.650	7.335	0.494	0.473
3	1.820	2	6.336	86.333	4.806	0.361	0.507
5	1.812	2	3.759	89.637	4.641	0.378	0.301
7	1.812	2	4.856	88.817	4.688	0.410	0.388
9	1.816	2	4.301	89.777	4.318	0.277	0.344
12	1.810	2	6.956	84.392	5.851	0.270	0.556
15	1.808	2	7.122	81.567	6.888	0.383	0.570
20	1.812	2	7.690	83.930	5.318	0.403	0.615

Table D.15 ME conversion in MCPO by using a 5:1 molar ratio of methanol to oil at a temperature of 65 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without GL (%wt)	TG without GL (%wt)	DG without GL (%wt)	MG without GL (%wt)	GL (%wt)
0	1.832	2	1.282	7.957	4.623	0.157	0.064
0.5	1.828	2	3.982	83.354	6.699	0.475	0.319
1	1.824	2	5.916	81.650	7.335	0.494	0.473
3	1.820	2	6.336	86.333	4.806	0.361	0.507
5	1.812	2	3.759	89.637	4.641	0.378	0.301
7	1.812	2	4.856	88.817	4.688	0.410	0.388
9	1.816	2	4.301	89.777	4.318	0.277	0.344
12	1.810	2	6.956	84.392	5.851	0.270	0.556
15	1.808	2	7.122	81.567	6.888	0.383	0.570
20	1.812	2	7.690	83.930	5.318	0.403	0.615

Table D.16 ME conversion in MCPO by using a 7.5:1 molar ratio of methanol to oil at a temperature of 55 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without GL (%wt)	TG without GL (%wt)	DG without GL (%wt)	MG without GL (%wt)	GL (%wt)
0	1.832	2	1.282	7.957	4.623	0.157	0.064
0.5	1.828	2	3.982	83.354	6.699	0.475	0.319
1	1.824	2	5.916	81.650	7.335	0.494	0.473
3	1.820	2	6.336	86.333	4.806	0.361	0.507
5	1.812	2	3.759	89.637	4.641	0.378	0.301
7	1.812	2	4.856	88.817	4.688	0.410	0.388
9	1.816	2	4.301	89.777	4.318	0.277	0.344
12	1.810	2	6.956	84.392	5.851	0.270	0.556
15	1.808	2	7.122	81.567	6.888	0.383	0.570
20	1.812	2	7.690	83.930	5.318	0.403	0.615

Table D.17 ME conversion in MCPO by using a 7.5:1 molar ratio of methanol to oil at a temperature of 60 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without GL (%wt)	TG without GL (%wt)	DG without GL (%wt)	MG without GL (%wt)	GL (%wt)
0	1.832	2	1.282	7.957	4.623	0.157	0.064
0.5	1.828	2	3.982	83.354	6.699	0.475	0.319
1	1.824	2	5.916	81.650	7.335	0.494	0.473
3	1.820	2	6.336	86.333	4.806	0.361	0.507
5	1.812	2	3.759	89.637	4.641	0.378	0.301
7	1.812	2	4.856	88.817	4.688	0.410	0.388
9	1.816	2	4.301	89.777	4.318	0.277	0.344
12	1.810	2	6.956	84.392	5.851	0.270	0.556
15	1.808	2	7.122	81.567	6.888	0.383	0.570
20	1.812	2	7.690	83.930	5.318	0.403	0.615

Table D.18 ME conversion in MCPO by using a 7.5:1 molar ratio of methanol to oil at a temperature of 65 degree Celsius

Time (min)	Weight (g)	Volume (cm^3)	ME without GL (%wt)	TG without GL (%wt)	DG without GL (%wt)	MG without GL (%wt)	GL (%wt)
0	1.832	2	1.282	7.957	4.623	0.157	0.064
0.5	1.828	2	3.982	83.354	6.699	0.475	0.319
1	1.824	2	5.916	81.650	7.335	0.494	0.473
3	1.820	2	6.336	86.333	4.806	0.361	0.507
5	1.812	2	3.759	89.637	4.641	0.378	0.301
7	1.812	2	4.856	88.817	4.688	0.410	0.388
9	1.816	2	4.301	89.777	4.318	0.277	0.344
12	1.810	2	6.956	84.392	5.851	0.270	0.556
15	1.808	2	7.122	81.567	6.888	0.383	0.570
20	1.812	2	7.690	83.930	5.318	0.403	0.615

APPENDIX E

ANALYTICAL DATA FOR THE TWO-STAGE PROCESS

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No. 8177/49 Page1/1

TEST REPORT

Client Name and Address : Mr. Surachai Jansri
Department of Mechanical Engineering, Faculty of Engineering,
Prince of Songkla University

Test Request Form No.: 9560/49 (refer to Test Request Form No. 8619/49 received date May 22, 2006)

Test item(s) received date : September 27, 2006

Analyst : Miss Sathida Malee

Test performed date : May 23, 2006

Test Method used : Refer to EN 14110:2003

Test Instrument : HP 6850 Gas Chromatograph with Flame Ionization Detector

Test Technique: Head Space-Gas Chromatography

Test Condition : Inlet temperature: 150°C
Oven temperature: 50°C 5 minutes
Detector temperature: 150°C
Column: Innowax , length 30 m., 250 µm I.D, 0.25 µm film thickness

Test item(s) description : Biodiesel from CPO **Quantity :** 3 Samples

Test Results :

No.	Sample	Methanol content ± standard deviation, %
1	V1 check CH_3OH	42.49 ± 0.49
2	V2 check CH_3OH	32.68 ± 3.03
3	V3 check CH_3OH	44.26 ± 0.36

LOQ of Methanol = 0.01%

Refer to Folder 8619-49

Patchara Sukonrat

(Miss Patchara Sukonrat)

Inspector

Remark This Test report is valid only for the tested sample.

Figure E.1 Remained methanol content in the first stage solution

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No.0016/50 Page 1/1

TEST REPORT

Client Name and Address : Mr. Surachai Jansri
Department of Mechanical Engineering, Faculty of Engineering
Prince of Songkla University

Test Request Form No.: 10245/49

Test item(s) received date : December 29, 2006

Analyst : Miss Pimpimol Penjamras

Test performed date : December 29, 2006

Test Method used : Refer to WI-RES- GC-001

Test Instrument : Agilent 6890 Gas Chromatograph with Flame Ionization Detector

Test Technique: Gas Chromatography

Test Condition : **Gas Chromatograph**

Inlet temperature: 250 °C
Oven initial temperature: 210 °C 30 minutes
Ramp to 250 °C 1 minute at 20 °C / minute
Column:HP-INNOWAX, 30 m., film thickness 0.25μm, ID. 0.25 mm
Detector temperature: 300 °C
Hydrogen flow: 30 ml/min
Air flow: 300 ml/min
Makeup flow: 25 ml/min

Test item(s) description : - **Quantity :** 4 Samples

Test Results :

No.	Sample name	The % wt. of	
		ester content (C), (SD)	linolenic acid methyl ester content (L), (SD)
1	MCPO	0.3, (0.009)	0.0
2	Esterification 5 min	8.8, (0.035)	0.4, (0.0006)
3	Esterification 10 min	9.8, (0.022)	0.4, (0.018)
4	Esterification 20 min	9.4, (0.066)	0.4, (0.008)

Refer to folder 9931_49

(Ms. Patchara Sukonrat)
Inspector

Remark This Test report is valid only for the tested sample.

Figure E.2 Ester content of first-stage process at different times

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No.8561/49 Page 1/1

TEST REPORT

Client Name and Address : Mr. Surachai Jansri
Department of Mechanical Engineering, Faculty of Engineering,
Prince of Songkla University

Test Request Form No.: 9932/49

Test item(s) received date : November 23, 2006

Analyst : Miss Pimpimol Penjamras

Test performed date : November 30, 2006

Test Method used : Refer to REF-RES-Wetlab-004

Test Instrument : -

Test Technique: Free fatty acid : Titrimetric Method

Test Condition : -

Test item(s) description : Crude palm oil **Quantity :** 1 Sample

Test Results :

Sample name	Free fatty acid value,(SD)
MCPO	9.4 mgKOH/ g, (0.1)

(Ms. Patchara Sukonrat)
Inspector

Remark This Test report is valid only for the tested sample.

Figure E.3 Free fatty acid value of MCPO

สำเนา

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No. 0291/50 Page1/1

TEST REPORT

Client Name and Address : Mr. Surachai Jansri
Department of Mechanical Engineering, Faculty of Engineering,
Prince of Songkla University

Test Request Form No.: 0096/50

Test item(s) received date : January 10, 2007

Analyst : Miss Sathida Malee

Test performed date : January 24-25, 2007

Test Method used : Refer to EN 14105:2003

Test Instrument : HP 6890 Gas Chromatograph with Flame Ionization Detector

Test Technique: Gas Chromatography

Test Condition : Inlet temperature: Track oven Detector temperature: 380°C
Oven initial temperature: 50°C, hold 1 minute
Ramp to : 180 ° C , at 15°C / minute
Ramp to : 230 ° C , at 7 ° C / minute
Ramp to : 370 ° C , at 10 ° C / minute, hold 5 minutes
Column: DB-5HT , length 15 m., 320 µm I.D, 0.1 µm film thickness plus
Retention gap, length 5 m., 320 µm I.D

Test item(s) description : Oil and glycerol **Quantity :** 1 Sample

Test Results :

Sample	Content (%RSD), %		
	Monoglyceride	Diglyceride	Triglyceride
MCPO	0.237 (0.994)	10.276 (1.217)	95.587 (0.738)

Patchara Sukonrat

(Miss Patchara Sukonrat)

Inspector

Remark This Test report is valid only for the tested sample.

Figure E.4 MG, DG and TG content in MCPO

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No. 1237/50 Page 1/1

TEST REPORT

Client Name and Address : Mr. Surachai Jansri
Department of Mechanical Engineering, Faculty of Engineering
Prince of Songkla University

Test Request Form No.: 1314/50

Test item(s) received date : May 21, 2007

Analyst : Miss Pimpimol Penjamras

Test performed date : May 24-26, 2007

Test Method used : Refer to WI-RES- GC-001

Test Instrument : Agilent 6890 Gas Chromatograph with Flame Ionization Detector

Test Technique: Gas Chromatography

Test Condition : **Gas Chromatograph**

Inlet temperature: 250 °C
Oven initial temperature: 50 °C 2 minutes
Ramp to 250 °C 7 minute at 10 °C / minute
Column:HP-INNOWAX, 30 m., film thickness 0.25μm, ID. 0.25 mm
Detector temperature: 300 °C
Hydrogen flow: 30 ml/min
Air flow: 300 ml/min
Makeup flow: 25 ml/min

Test item(s) description : Biodiesel (B100) **Quantity :** 1 Sample

Test Results :

Sample name	The % wt. of	
	The % ester C content, (SD)	The % Linolenic acid methyl ester content, (SD)
Mix-CPOME	93.2, (0.4)	0.3,(0.003)
Limit range	Minimum 96.5 %	Maximun 12 %

Refer to folder 1314_50

(Ms. Patchara Sukonrat)
Inspector

Remark This Test report is valid only for the tested sample.

Figure E.5 The % ester content of biodiesel produce from MCPO

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No. 1082 / 50 Page 1 / 1

TEST REPORT

Client Name and Address : Mr. Surachai Jansri
Department of Mechanical Engineering, Faculty of Engineering, PSU.

Test Request Form No.: 1222 / 50 (Refers to F-ASO-022 No. 1146/50, April 30, 2007)

Test item(s) received date : May 9, 2007

Analyst : Miss Sunaree Bordeepong

Test performed date : May 1, 2007

Test Method used : Refer to WI-RES-Hydrometer-001, REF-RES-ASTM D1298-99^{E2} และ REF-RES-ASTM D 1250-04
S/W-RES-Hydrometer-001

Test Instrument : Hydrometer

Test Technique: -

Test Condition : Objective : Density ASTM D1298

Test item(s) description : Biodiesel (B100) **Quantity :** 1 sample

Test Result :

No.	Sample	Density at 15 ^{o}C (kg/m^3)	%RSD
1	MIX-CPOME	878.7	0.02

Patchara Sukonrat

(Miss Patchara Sukonrat)

Inspector

Remark This Test report is valid only for the tested sample.

Figure E.6 Density of biodiesel prepared from MCPO

Code 58

Dept. of Chemical Engineering ,Faculty of Engineering
Prince of Songkla University
HatYai Songkla 90112 Tel/Fax 0-7421-2896

Customer: Mr.Surachai Jansri
Department of Mechanical Engineering.
Date : May 1, 2007
Sample : Mix-CPOME

Item	Results
Flash point (°C)	167
Viscosity @ 40 °C (cSt)	5.28
Copper strip corrosion	No.1a

Analyst : Sorawit Jitbunjerdkul

Pakamas

(Asst.Prof. Pakamas Jespatananon,Ph.D)

Figure E.7 Flash point and viscosity of biodiesel from MCPO

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No. 1057 / 50 Page 1 / 1

TEST REPORT

Client Name and Address : Mr.Surachai Jansri
Department of Mechanical Engineering, Faculty of Engineering, Prince of Songkla University

Test Request Form No.: 1149 / 50

Test item(s) received date : April 30, 2007

Analyst : Ms.Patchara Sukonrat

Test performed date : May 4, 2007

Test Method used : Refer to WI-RES-XRF-001 and WI-RES-XRF-002

Test Instrument : X-ray fluorescence spectrometer (PHILIPS, PW2400)

Test Technique: X-ray fluorescence spectrometry

Test Condition : X-ray tube : Rh tube X-ray path : Helium
Application : S in Oil Sample preparation : Liquid cup with 6μ polypropelene
Objective : S

Test item(s) description : Biodiesel (B100) **Quantity :** 1 Sample

Test Results :

No.	Sample	Sulphur(%)	RMS
1	Mix-CPOME	0.0004	0.0001

(Mr.Terdtoon Dumrongrittamatt)
Inspector

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Figure E.8 Sulphur content of biodiesel made from MCPO

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No. 1116/50 Page1/1

TEST REPORT

Client Name and Address : Mr. Surachai Jansri
Department of Mechanical Engineering, Faculty of Engineering, Prince of Songkla University

Test Request Form No.: 1151/50

Test item(s) received date : April 30, 2007

Analyst : Miss Waraporn Ratsameepakai

Test performed date : May 9-14, 2007

Test Method used : Refer to REF-ASTM D 874-00

Test Instrument : High Temperature Furnace

Test Technique: Gravimetric method

Test Condition : Ignite at 775 ± 25 °C

Test item(s) description : Biodiesel (B100) **Quantity :** 1 sample

Test Result:

No.	Sample Name	Sulfate Ash, mass % : (%RSD)
1	Mix-CPOME	0.0050 (0.0004)

Limit of the method 0.005 mass %

Patchara Sukonrat

(Ms. Patchara Sukonrat)

Inspector

Remark This Test report is valid only for the tested sample.

Figure E.9 Sulphur ash content of biodiesel made from MCPO

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F-RES-003I/E Rev. 4 23/08/47

No. 1105/50 Page 1/1

TEST REPORT

Client Name and Address :	Mr. Surachai Jansri
	Department of Mechanical Engineering, Faculty of Engineering, PSU.
Test Request Form No.:	1223/50 (Refer : F-ASO-022 No. 1148/50 Date; April 30, 2007)
Test item(s) received date :	May 9, 2007
Analyst :	Ms. Wachiraporn Thongbun
Test performed date :	May 2, 2007
Test Method used :	Refer to REF-RES-ASTM D 2709-96
Test Instrument :	Centrifuge (Koehler Benchmark 2000)
Test Technique:	Centrifuge
Test Condition :	Relative centrifuge force (rcf) 800 ± 60
Test item(s) description :	Biodiesel (B100) **Quantity** : 1 sample

Test Result :

No.	Sample	Volumetric percent of water and sediment
1	Mix-CPOME	<0.05%

(Ms. Patchara Sukonrat)
Inspector

Remark This Test report is valid only for the tested sample.

Figure E.10.1 Water and sediment in biodiesel obtained from MCPO

Attachment data of sample (Refer: F-ASO-022 No. 1148/50)

- **Mix-CPOME**

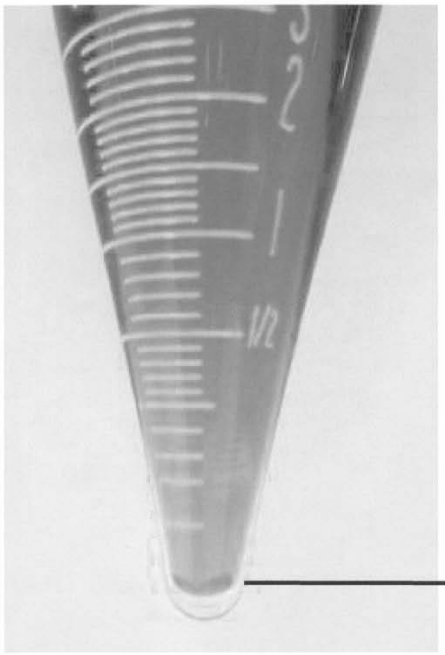

Figure E.10.2 Water and sediment in biodiesel obtained from MCPO

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No.1076/50 Page 1/1

TEST REPORT

Client Name and Address : Mr. Surachai Jansri
Department of Mechanical Engineering, Faculty of Engineering, PSU.

Test Request Form No.: 1224/50

Test item(s) received date : May 9, 2007 (refer to F-ASO-022 No. 1150/50 date April 30, 2007)

Analyst : Miss Songsuda Promthong

Test performed date : May 2, 2007

Test Method used : In house method refer to ASTM D664-01

Test Instrument : 794 Basic Titrino (Potentiometric Autotitrator)

Test Technique: Potentiometric Titration

Test Condition : -

Test item(s) description : Biodeisel (B100) **Quantity :** 1 Sample

Test Results :

No.	Sample Name	Acid Number (mgKOH/g)	%RSD
1	Mix - CPOME	0.25	1.22

* The result is refered to folder 1150-50

Patchara Sukonrat

(Ms.Patchara Sukonrat)
Inspector

Remark This Test report is valid only for the tested sample.

Figure E.11 Acid number of biodiesel made from MCPO

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No. 1122/50 Page1/1

TEST REPORT

Client Name and Address : Mr. Surachai Jansri
Department of Mechanical Engineering, Faculty of Engineering,
Prince of Songkla University.

Test Request Form No.: 1147/50

Test item(s) received date : April 30, 2007

Analyst : Miss Sathida Malee

Test performed date : May 13, 2007

Test Method used : Refer to EN 14105:2003

Test Instrument : HP 6890 Gas Chromatograph with Flame Ionization Detector

Test Technique: Gas Chromatography

Test Condition : Inlet temperature: Track oven Detector temperature: 380°C
Oven initial temperature: 50°C, hold 1 minute
Ramp to : 180 ° C , at 15°C / minute
Ramp to : 230 ° C , at 7 ° C / minute
Ramp to : 370 ° C , at 10 ° C / minute, hold 5 minutes
Column: Select Biodiesel for Glycerides , length 10 m., 320 µm I.D, 0.1 µm film thickness plus
Retention gap, length 2 m., 530 µm I.D

Test item(s) description : Biodiesel (B100) **Quantity :** 1 Sample

Test Results :

Sample	Content (%RSD), %				
	Free glycerol	Monoglyceride	Diglyceride	Triglyceride	Total glycerol
Mix_CPOME	ไม่พบ	0.65 (0.37)	0.78 (2.43)	7.55 (1.81)	1.06 (1.13)
Standard criteria	≤ 0.02	≤ 0.80	≤ 0.20	≤ 0.20	≤ 0.25

Refer to Folder 1147_50

(Miss Patchara Sukonrat)
Inspector

Remark This Test report is valid only for the tested sample.

Figure E.12 Free GL, MG, DG, TG, and total GL in biodiesel produced from MCPO

APPENDIX F

% DATA ERROR MEAN AND STANDARD DEVIATION IN CATEGORIES OF THE TWO-STAGE PROCESS FROM MATLAB7 CURVE FITTING TOOL

Table F.1 Rate coefficients and reaction orders of esterification from MATLAB7

Conditions for Reducing FFA in MCPO (MeOH: FFA; Temperature) (Molar Ratios; Degree Celsius)	**Rate Coefficients and Reaction Orders of Esterification**						
	k_1 (min-1)	a	b	k_2 (min-1)	c	d	R^2
4:1;55	1.985	0.982	0.279	0.452	0.190	0.218	0.950
4:1;60	2.804	1.720	0.587	0.444	0.392	0.570	0.964
4:1;65	2.135	0.311	1.667	2.205	0.417	0.138	0.922
10:1;55	0.697	0.592	0.792	1.022	0.001	0.086	0.848
10:1;60	0.837	0.278	0.976	1.259	0.224	0.078	0.916
10:1;65	0.802	0.622	0.973	0.781	0.356	0.291	0.904
16:1;55	1.035	0.123	0.746	10.380	0.376	0.445	0.962
16:1;60	0.826	0.490	0.560	0.172	0.004	0.382	0.927
16:1;65	0.883	0.312	0.502	1.620	0.179	0.315	0.970

Table F.2 Rate coefficients of transesterification from MATLAB7

Conditions for Producing CPOME (MeOH: TG; Temperature) (Molar Ratios; Degree Celsius)	**Rate Conefficients of Transesterification** (min-1)						
	k_3	k_4	k_5	k_6	k_7	k_8	R^2
3:1;55	1.977	0.215	1.278	0.755	0.458	0.074	0.970
3:1;60	1.669	0.211	1.359	0.525	0.607	0.065	0.975
3:1;65	1.698	0.282	1.358	0.420	0.612	0.055	0.970
6:1;55	1.454	0.100	1.049	0.141	0.508	0.049	0.979
6:1;60	1.474	0.086	1.197	0.043	0.623	0.011	0.974
6:1;65	1.509	0.098	1.086	0.068	0.558	0.008	0.974
9:1;55	1.487	0.152	1.205	0.072	0.615	0.013	0.976
9:1;60	1.177	0.102	1.002	0.077	0.548	0.008	0.986
9:1;65	1.233	0.217	0.985	0.152	0.591	0.003	0.992

Formula for calculating mean and standard deviation in categories (Exell, 2005)

Suppose a population of n measurements $x_{i,j}$ is divided into m categories of m categories of sizes n_i having mean μ_i and standard deviation σ_i, where i=1,...,m, as follows:

$$\mu = \frac{x_{i,1} + ... + x_{i,n_1}}{n_i},$$

$$\sigma = \left[\frac{(x_{i,1} - \mu_i)^2 + ... + (x_{i,n_i} - \mu_i)^2}{n_i} \right]^{\frac{1}{2}}$$

For all population:

$$n = n_1 + ... + n_m,$$

$$\mu = \frac{n_1\mu_1 + ... + n_m\mu_m}{n},$$

$$\sigma = \left[\frac{n_1\sigma_1^2 + ... + n_m\sigma_m^2}{n} + \frac{n_1(\mu_1 - \mu)^2 + ... + n_m(\mu_m - \mu)^2}{n} \right]^{\frac{1}{2}}$$

The first in the last expression for σ is the mean of the category variances, and the second term is the variance of the category mean.

Table F.3 Comparison between the % data error mean and the standard deviation in categories of the two-stage process between raw data and MATLAB7

Categories of % data error	**n**	**μ**	**σ**
Esterification (MeOH: FFA; Temperature) (Molar Ratios; Degree Celsius)			
4:1;55	40	15	14
4:1;60	40	35	41
4:1;65	40	28	33
10:1;55	40	36	36
10:1;60	40	24	26
10:1;65	40	55	113
16:1;55	40	25	43
16:1;60	40	82	168
16:1;65	40	19	27
Transesterification (MeOH: TG; Temperature) (Molar Ratios; Degree Celsius)			
3:1;55	60	454	835
3:1;60	60	272	407
3:1;65	60	395	712
6:1;55	60	144	313
6:1;60	60	98	416
6:1;65	60	184	1,144
9:1;55	60	32	34
9:1;60	60	45	93
9:1;65	60	42	39
Whole population	**900**	**125**	**467**