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## APPENDICES

### Appendix A Soap Formation Results for Sodium Methoxide (NaOCH<sub>3</sub>) Catalyst

**Table A1** Soap formation results for Sodium methoxide (NaOCH<sub>3</sub>) catalyst at catalyst concentration of 0.59 wt%, 4.8:1 methanol/oil molar ratio and 90°C

Conditions (Sample No.)	soap (g) / sample (g)	Soap (ppm)	Average of titrations	Average of repeated reactions	Standard deviation
800 rpm (1)	1.16E-003	1155.96	1132.37	931.84	283.58
800 rpm (2)	1.11E-003	1108.78			
800 rpm (3)	7.55E-004	754.91	731.32		
800 rpm (4)	7.08E-004	707.73			
800-400 rpm (1)	1.51E-003	1509.82	1226.73	1209.04	25.02
800-400rpm (2)	1.23E-003	1226.73			
800-400 rpm (3)	1.23E-003	1226.73			
800-400 rpm (4)	1.19E-003	1191.35	1191.35		
800-400 rpm (5)	1.19E-003	1191.35			

**Table A2** Soap formation results for Sodium methoxide (NaOCH<sub>3</sub>) catalyst at catalyst concentration of 0.59 wt%, 4.8:1 methanol/oil molar ratio and mixing rate 800 rpm

Conditions (Sample No.)	soap (g) / sample (g)	Soap (ppm)	Average of titrations	Average of repeated reactions	Standard deviation
800rpm/70°C (1)	1.42E-003	1415.46	1409.56	1341.74	95.92
800rpm/70°C (2)	1.40E-003	1403.66			
800rpm/70°C (3)	1.27E-003	1273.91	1273.91		
800rpm/70°C (4)	1.27E-003	1273.91			
800rpm/80°C (1)	1.30E-003	1297.51	1297.51	1256.22	58.38
800rpm/80°C (2)	1.30E-003	1297.51			
800rpm/80°C (3)	1.20E-003	1203.14	1214.94		
800rpm/80°C (4)	1.23E-003	1226.73			

**Table A3** Soap formation results for Sodium methoxide (NaOCH<sub>3</sub>) catalyst at catalyst concentration of 0.59 wt%, mixing rate 800 rpm and 90°C

Conditions (Sample No.)	soap (g) / sample (g)	Soap (ppm)	Average of titrations	Average of repeated reactions	Standard deviation
3:1 Methanol/Oil (1)	8.49E-004	849.276	861.07	902.36	58.38
3:1 Methanol/Oil (2)	8.73E-004	872.867			
3:1 Methanol/Oil (3)	1.18E-003	1179.55	943.64		
3:1 Methanol/Oil (4)	7.08E-004	707.73			
4.5:1 Methanol/Oil (1)	1.06E-003	1061.595	1049.80	1002.62	66.73
4.5:1 Methanol/Oil (2)	1.04E-003	1038.004	955.44		
4.5:1 Methanol/Oil (3)	9.67E-004	967.231			
4.5:1 Methanol/Oil (4)	9.44E-004	943.64			
4.8:1 Methanol/Oil (1)	1.44E-003	1439.051	1427.26	1273.91	216.86
4.8:1 Methanol/Oil (2)	1.42E-003	1415.46	1120.57		
4.8:1 Methanol/Oil (3)	1.11E-003	1108.777			
4.8:1 Methanol/Oil (4)	1.13E-003	1132.368			
6:1 Methanol/Oil (1)	1.89E-003	1887.28	1887.28	1846.00	58.38
6:1 Methanol/Oil (2)	1.89E-003	1887.28	1804.71		
6:1 Methanol/Oil (3)	1.79E-003	1792.916			
6:1 Methanol/Oil (4)	1.82E-003	1816.507			

**Table A4** Soap formation results for Sodium methoxide (NaOCH<sub>3</sub>) catalyst at 4.5:1 methanol/oil molar ratio, mixing rate 800 rpm and 90°C

Conditions (Sample No.)	soap (g) / sample (g)	Soap (ppm)	Average of titrations	Average of repeated reactions	Standard deviation
0.10% NaOCH <sub>3</sub> (1)	1.67E-003	1674.961	1686.76	2188.07	708.96
0.10% NaOCH <sub>3</sub> (2)	1.70E-003	1698.552			
0.10% NaOCH <sub>3</sub> (3)	2.69E-003	2689.374	2689.37		
0.10% NaOCH <sub>3</sub> (4)	2.69E-003	2689.374			
0.25% NaOCH <sub>3</sub> (1)	1.58E-003	1580.597	1580.60	1444.95	191.84
0.25% NaOCH <sub>3</sub> (2)	1.58E-003	1580.597	1309.30		
0.25% NaOCH <sub>3</sub> (3)	1.32E-003	1321.096			
0.25% NaOCH <sub>3</sub> (4)	1.30E-003	1297.505			
0.50% NaOCH <sub>3</sub> (1)	1.37E-003	1368.278	1368.28	1309.30	83.41
0.50% NaOCH <sub>3</sub> (2)	1.37E-003	1368.278	1250.32		
0.50% NaOCH <sub>3</sub> (3)	1.25E-003	1250.323			
0.50% NaOCH <sub>3</sub> (4)	1.25E-003	1250.323			
0.59% NaOCH <sub>3</sub> (1)	1.06E-003	1061.595	1049.80	1002.62	66.73
0.59% NaOCH <sub>3</sub> (2)	1.04E-003	1038.004	955.44		
0.59% NaOCH <sub>3</sub> (3)	9.67E-004	967.231			
0.59% NaOCH <sub>3</sub> (4)	9.44E-004	943.64			
0.65% NaOCH <sub>3</sub> (1)	1.42E-003	1415.46	1403.66	701.83	-
0.65% NaOCH <sub>3</sub> (2)	1.39E-003	1391.869			
0.75% NaOCH <sub>3</sub> (3)	1.58E-003	1580.597	1592.39	1604.19	16.68
0.75% NaOCH <sub>3</sub> (4)	1.60E-003	1604.188	1615.98		
0.75% NaOCH <sub>3</sub> (1)	1.63E-003	1627.779			
0.75% NaOCH <sub>3</sub> (2)	1.60E-003	1604.188			

**Table A5** Soap formation results for Sodium methoxide ( $\text{NaOCH}_3$ ) catalyst at mixing rate 800 rpm

Conditions (Sample No.)	soap (g) / sample (g)	Soap (ppm)	Average of Titrations
Catalyst Conc. 0.59 wt% - 6:1 Methanol/Oil - T = 90°C (1)	1.70E-003	1,704.64	1596.61
Catalyst Conc. 0.59 wt% - 6:1 Methanol/Oil - T = 90°C (2)	1.49E-003	1,488.58	
Catalyst Conc. 1.00 wt% - 6:1 Methanol/Oil - T = 90°C (1)	2.40E-003	2,404.76	2387.17
Catalyst Conc. 1.00 wt% - 6:1 Methanol/Oil - T = 90°C (2)	2.37E-003	2,369.58	
Catalyst Conc. 1.50 wt% - 6:1 Methanol/Oil - T = 90°C (1)	4.86E-003	4,860.68	4865.54
Catalyst Conc. 1.50 wt% - 6:1 Methanol/Oil - T = 90°C (2)	4.87E-003	4,870.40	
3.5:1 Methanol/Oil - T = 90°C - Catalyst Conc. 0.59 wt% (1)	4.57E-004	456.60	532.70
3.5:1 Methanol/Oil - T = 90°C - Catalyst Conc. 0.59 wt% (2)	6.09E-004	608.80	
4.5:1 Methanol/Oil - T = 90°C - Catalyst Conc. 0.59 wt% (1)	1.03E-003	1,032.89	1032.89
4.5:1 Methanol/Oil - T = 90°C - Catalyst Conc. 0.59 wt% (2)	1.03E-003	1,032.89	
T = 60°C - Catalyst Conc. 0.59 wt% - 6:1 Methanol/Oil (1)	1.83E-003	1,826.40	1856.84
T = 60°C - Catalyst Conc. 0.59 wt% - 6:1 Methanol/Oil (2)	1.89E-003	1,887.28	
T = 70°C - Catalyst Conc. 0.59 wt% - 6:1 Methanol/Oil (1)	2.04E-003	2,035.41	2067.88
T = 70°C - Catalyst Conc. 0.59 wt% - 6:1 Methanol/Oil (2)	2.10E-003	2,100.36	

## Appendix B Determination of Biodiesel Yield using $^1\text{H-NMR}$ Analysis for Sodium Methoxide ( $\text{NaOCH}_3$ ) Catalyst

**Table B1**  $^1\text{H-NMR}$  results for Sodium methoxide ( $\text{NaOCH}_3$ ) catalyst at catalyst concentration of 0.59 wt% (6:1 methanol/oil ratio, temperature  $90^\circ\text{C}$ , mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm		Yield (%)		Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	301.58	275.71	66.317	72.540	69.429	4.4000
60 s	300	289.72	256.24	69.032	78.052	73.542	6.3778
90 s	300	271.38	244.65	73.697	81.749	77.723	5.6937
120 s	300	263.36	245.25	75.942	81.549	78.746	3.9653
150 s	300	244.33	245.66	81.857	81.413	81.635	0.3134
180 s	300	243.38	240.95	82.176	83.005	82.590	0.5860
5 min	300	243.00	230.14	82.305	86.904	84.604	3.2521
10 min	300	220.3	234.50	90.785	85.288	88.037	3.8873
20 min	300	217.85	220.62	91.806	90.654	91.230	0.8151
30 min	300	217.45	222.59	91.975	89.851	90.913	1.5018
40 min	300	214.75	221.84	93.132	90.155	91.643	2.1047
60 min	300	224.89	219.09	88.932	91.287	90.110	1.6648

**Table B2**  $^1\text{H-NMR}$  results for Sodium methoxide ( $\text{NaOCH}_3$ ) catalyst at catalyst concentration of 1.00 wt% (6:1 methanol/oil ratio, temperature  $90^\circ\text{C}$ , mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	228.37	247.12	87.577	80.932	84.255	4.6986
60 s	300	237.89	229.34	84.072	87.207	85.640	2.2163
90 s	300	230.38	224.76	86.813	88.984	87.898	1.5349
120 s	300	233.56	223.65	85.631	89.425	87.528	2.6830
150 s	300	229.80	220.58	87.032	90.670	88.851	2.5723
180 s	300	215.84	226.53	92.661	88.289	90.475	3.0920
5 min	300	221.76	227.15	90.188	88.048	89.118	1.5132
10 min	300	218.12	217.15	91.693	92.102	91.897	0.2896
20 min	300	220.37	227.12	90.756	88.059	89.408	1.9073
30 min	300	226.46	222.24	88.316	89.993	89.154	1.1858
40 min	300	222.30	222.92	89.969	89.718	89.843	0.1769
60 min	300	228.56	223.00	87.504	89.686	88.595	1.5427

**Table B3**  $^1\text{H-NMR}$  results for Sodium methoxide ( $\text{NaOCH}_3$ ) catalyst at catalyst concentration of 1.50 wt% (methanol to oil ratio 6:1, temperature  $90^\circ\text{C}$ , mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	239.51	239.54	83.504	83.493	83.499	0.0074
60 s	300	239.08	232.46	83.654	86.036	84.845	1.6845
90 s	300	224.93	240.25	88.917	83.247	86.082	4.0092
120 s	300	226.12	228.14	88.449	87.665	88.057	0.5538
150 s	300	225.00	216.17	88.889	92.520	90.704	2.5674
180 s	300	222.04	221.58	90.074	90.261	90.167	0.1322
5 min	300	228.84	226.58	87.397	88.269	87.833	0.6164



**Table B3 (Cont.)** <sup>1</sup>H-NMR results for Sodium methoxide (NaOCH<sub>3</sub>) catalyst at catalyst concentration of 1.50 wt% (methanol to oil ratio 6:1, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
10 min	300	229.31	223.78	87.218	89.373	88.296	1.5240
20 min	300	218.25	222.89	91.638	89.730	90.684	1.3489
30 min	300	225.61	234.05	88.649	85.452	87.050	2.2604
40 min	300	220.70	232.12	90.621	86.162	88.392	3.1526
60 min	300	220.22	233.09	90.818	85.804	88.311	3.5458

**Table B4** <sup>1</sup>H-NMR results for Sodium methoxide (NaOCH<sub>3</sub>) catalyst at methanol to oil ratio of 4.5:1 (catalyst concentration 0.59 wt%, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	272.45	286.66	73.408	69.769	71.589	2.5731
60 s	300	262.82	262.04	76.098	76.324	76.211	0.1602
90 s	300	257.63	267.58	77.631	74.744	76.187	2.0412
120 s	300	250.27	250.82	79.914	79.738	79.826	0.1239
150 s	300	247.57	254.78	80.785	78.499	79.642	1.6165
180 s	300	241.57	252.24	82.792	79.290	81.041	2.4764
5 min	300	238.88	233.6	83.724	85.616	84.670	1.3381
10 min	300	229.15	231.74	87.279	86.304	86.791	0.6898
20 min	300	228.06	221.61	87.696	90.249	88.972	1.8048
30 min	300	226.88	224.17	88.152	89.218	88.685	0.7535
40 min	300	224.33	219.68	89.154	91.042	90.098	1.3344
60 min	300	227.66	222.71	87.850	89.803	88.827	1.3807

**Table B5**  $^1\text{H-NMR}$  results for Sodium methoxide ( $\text{NaOCH}_3$ ) catalyst at methanol to oil ratio of 3.5:1 (catalyst concentration 0.59 wt%, temperature  $90^\circ\text{C}$ , mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	288.77	306.16	69.259	65.325	67.292	2.7817
60 s	300	271.72	291.07	73.605	68.712	71.159	3.4600
90 s	300	255.26	283.60	78.351	70.522	74.437	5.5364
120 s	300	248.84	277.13	80.373	72.168	76.271	5.8016
150 s	300	251.33	271.04	79.577	73.790	76.683	4.0919
180 s	300	254.77	277.11	78.502	72.174	75.338	4.4750
5 min	300	243.27	264.21	82.213	75.697	78.955	4.6074
10 min	300	238.27	244.46	83.938	81.813	82.876	1.5029
20 min	300	235.04	235.84	85.092	84.803	84.948	0.2041
30 min	300	228.11	235.74	87.677	84.839	86.258	2.0066
40 min	300	221.79	231.50	90.175	86.393	88.284	2.6745
60 min	300	223.38	235.43	89.534	84.951	87.242	3.2404

**Table B6**  $^1\text{H-NMR}$  results for Sodium methoxide ( $\text{NaOCH}_3$ ) catalyst at temperature of  $70^\circ\text{C}$  (catalyst concentration 0.59 wt%, methanol to oil ratio 6:1, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	285.70	285.70	70.004	70.004	70.004	0.0000
60 s	300	267.16	298.01	74.862	67.112	70.987	5.4798
90 s	300	271.20	275.47	73.746	72.603	73.175	0.8083
120 s	300	263.93	263.70	75.778	75.844	75.811	0.0467
150 s	300	258.04	253.42	77.507	78.920	78.214	0.9991
180 s	300	256.59	250.02	77.945	79.994	78.969	1.4483
5 min	300	246.75	243.28	81.054	82.210	81.632	0.8175
10 min	300	233.98	236.01	85.477	84.742	85.110	0.5199
20 min	300	235.66	234.74	84.868	85.201	85.034	0.2352
30 min	300	220.77	233.91	90.592	85.503	88.047	3.5985

**Table B6 (Cont.)**  $^1\text{H-NMR}$  results for Sodium methoxide ( $\text{NaOCH}_3$ ) catalyst at temperature of  $70^\circ\text{C}$  (catalyst concentration 0.59 wt%, methanol to oil ratio 6:1, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
40 min	300	230.65	230.33	86.711	86.832	86.772	0.0852
60 min	300	227.63	215.99	87.862	92.597	90.229	3.3481

**Table B7**  $^1\text{H-NMR}$  results for Sodium methoxide ( $\text{NaOCH}_3$ ) catalyst at temperature of  $60^\circ\text{C}$  (catalyst concentration 0.59 wt%, methanol to oil ratio 6:1, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	374.20	368.77	53.447	54.234	53.841	0.5565
60 s	300	308.47	301.76	64.836	66.278	65.557	1.0194
90 s	300	294.53	283.34	67.905	70.587	69.246	1.8963
120 s	300	276.91	261.33	72.226	76.532	74.379	3.0448
150 s	300	271.11	259.15	73.771	77.175	75.473	2.4074
180 s	300	263.20	256.58	75.988	77.948	76.968	1.3863
5 min	300	249.86	237.05	80.045	84.370	82.208	3.0586
10 min	300	238.10	234.96	83.998	85.121	84.560	0.7938
20 min	300	234.90	223.73	85.143	89.393	87.268	3.0058
30 min	300	230.13	218.85	86.907	91.387	89.147	3.1674
40 min	300	235.59	240.00	84.893	83.333	84.113	1.1030
60 min	300	231.55	229.75	86.374	87.051	86.713	0.4785

**Appendix C Determination of Biodiesel Yield using  $^1\text{H-NMR}$  Analysis for 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD) Catalyst**

**Table C1**  $^1\text{H-NMR}$  results for 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD) catalyst at catalyst concentration of 1.53 wt% (6:1 methanol/oil molar ratio, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	263.33	308.50	75.950	64.830	70.390	7.8634
60 s	300	266.21	270.27	75.129	74.000	74.564	0.7980
90 s	300	262.40	280.82	76.220	71.220	73.720	3.5352
120 s	300	263.04	255.46	76.034	78.290	77.162	1.5953
150 s	300	259.99	260.79	76.926	76.690	76.808	0.1669
180 s	300	258.39	252.26	77.402	79.283	78.343	1.3300
5 min	300	232.99	243.36	85.841	82.183	84.012	2.5865
10 min	300	229.50	239.72	87.146	83.431	85.288	2.6271
20 min	300	231.36	221.88	86.445	90.139	88.292	2.6117
30 min	300	222.82	226.94	89.759	88.129	88.944	1.1523
40 min	300	218.18	218.55	91.667	91.512	91.590	0.1097
60 min	300	224.20	225.33	89.206	88.759	88.982	0.3163

**Table C2**  $^1\text{H-NMR}$  results for 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD) catalyst at catalyst concentration of 2.29 wt% (6:1 methanol/oil molar ratio, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	226.87	257.03	88.156	77.812	82.984	7.3145
60 s	300	235.04	239.06	85.092	83.661	84.376	1.0118
90 s	300	231.65	234.25	86.337	85.379	85.858	0.6776

**Table C2 Cont.** <sup>1</sup>H-NMR results for 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD) catalyst at catalyst concentration of 2.29 wt% (6:1 methanol/oil molar ratio, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm		Yield (%)		Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
120 s	300	238.15	234.96	83.981	85.121	84.551	0.8062
150 s	300	239.30	233.68	83.577	85.587	84.582	1.4213
180 s	300	243.43	236.55	82.159	84.549	83.354	1.6897
5 min	300	233.03	229.82	85.826	87.025	86.425	0.8477
10 min	300	231.90	223.36	86.244	89.542	87.893	2.3317
20 min	300	221.04	221.56	90.481	90.269	90.375	0.1502
30 min	300	227.32	233.07	87.982	85.811	86.896	1.5348
40 min	300	226.72	218.64	88.215	91.475	89.845	2.3052
60 min	300	229.32	218.93	87.214	91.353	89.284	2.9267

**Table C3** <sup>1</sup>H-NMR results for 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD) catalyst at catalyst concentration of 3.05 wt% (6:1 methanol/oil molar ratio, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm		Yield (%)		Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	229.39	225.80	87.188	88.574	87.881	0.9802
60 s	300	235.50	229.91	84.926	86.991	85.958	1.4601
90 s	300	216.93	224.15	92.196	89.226	90.711	2.0999
120 s	300	228.92	229.59	87.367	87.112	87.239	0.1803
150 s	300	215.53	223.22	92.795	89.598	91.196	2.2605
180 s	300	227.68	223.13	87.843	89.634	88.738	1.2666
5 min	300	218.55	224.89	91.512	88.932	90.222	1.8242
10 min	300	229.64	224.71	87.093	89.004	88.048	1.3511
20 min	300	227.95	216.78	87.739	92.259	89.999	3.1968
30 min	300	228.51	220.03	87.524	90.897	89.210	2.3852

**Table C3 Cont.** <sup>1</sup>H-NMR results for 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD) catalyst at catalyst concentration of 3.05 wt% (6:1 methanol/oil molar ratio, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
40 min	300	225.11	225.60	88.845	88.652	88.749	0.1365
60 min	300	223.37	218.52	89.538	91.525	90.531	1.4052

**Table C4** <sup>1</sup>H-NMR results for 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD) catalyst at methanol to oil molar ratio of 4.5:1 (catalyst concentration 2.29 wt%, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	231.05	237.84	86.561	84.090	85.326	1.7474
60 s	300	229.55	231.44	87.127	86.415	86.771	0.5031
90 s	300	226.63	226.06	88.250	88.472	88.361	0.1573
120 s	300	227.41	228.69	87.947	87.455	87.701	0.3481
150 s	300	239.26	233.29	83.591	85.730	84.661	1.5126
180 s	300	231.92	228.15	86.237	87.662	86.949	1.0076
5 min	300	228.80	223.00	87.413	89.686	88.549	1.6076
10 min	300	225.47	229.55	88.704	87.127	87.915	1.1148
20 min	300	222.26	222.62	89.985	89.839	89.912	0.1029
30 min	300	224.71	220.74	89.004	90.604	89.804	1.1319
40 min	300	225.69	225.41	88.617	88.727	88.672	0.0778
60 min	300	222.37	220.27	89.940	90.798	90.369	0.6063

**Table C5**  $^1\text{H-NMR}$  results for 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD) catalyst at methanol to oil molar ratio of 3.5:1 (catalyst concentration 2.29 wt%, temperature  $90^\circ\text{C}$ , mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	232.30	237.88	86.096	84.076	85.086	1.4280
60 s	300	228.66	239.88	87.466	83.375	85.421	2.8928
90 s	300	229.41	227.74	87.180	87.819	87.500	0.4520
120 s	300	248.96	240.09	80.334	83.302	81.818	2.0986
150 s	300	230.25	232.12	86.862	86.162	86.512	0.4948
180 s	300	231.71	229.80	86.315	87.032	86.673	0.5073
5 min	300	230.40	233.52	86.806	85.646	86.226	0.8201
10 min	300	222.52	227.22	89.880	88.020	88.950	1.3146
20 min	300	216.76	222.63	92.268	89.835	91.052	1.7202
30 min	300	222.01	223.33	90.086	89.554	89.820	0.3765
40 min	300	215.83	212.93	92.666	93.928	93.297	0.8924
60 min	300	221.67	210.26	90.224	95.120	92.672	3.4621

**Table C6**  $^1\text{H-NMR}$  results for 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD) catalyst at temperature of  $70^\circ\text{C}$  (catalyst concentration 2.29 wt%, 3.5:1 methanol/oil molar ratio, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	235.07	239.46	85.081	83.521	84.301	1.1029
60 s	300	231.40	234.63	86.430	85.241	85.836	0.8413
90 s	300	238.17	233.27	83.974	85.738	84.856	1.2473
120 s	300	234.18	232.17	85.404	86.144	85.774	0.5228
150 s	300	234.95	239.39	85.124	83.546	84.335	1.1164
180 s	300	235.56	235.53	84.904	84.915	84.909	0.0076
5 min	300	227.37	226.24	87.962	88.402	88.182	0.3107

**Table C6 (Cont.)** <sup>1</sup>H-NMR results for 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD) catalyst at temperature of 70°C (catalyst concentration 2.29 wt%, 3.5:1 methanol/oil molar ratio, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
10 min	300	228.97	226.78	87.348	88.191	87.769	0.5965
20 min	300	229.27	226.8	87.233	88.183	87.708	0.6718
30 min	300	227.22	221.81	88.020	90.167	89.094	1.5180
40 min	300	220.54	223.65	90.686	89.425	90.056	0.8917
60 min	300	218.90	221.55	91.366	90.273	90.819	0.7728

**Table C7** <sup>1</sup>H-NMR results for 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD) catalyst at temperature of 60°C (catalyst concentration 2.29 wt%, 3.5:1 methanol/oil molar ratio, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	232.30	236.62	86.096	84.524	85.310	1.1115
60 s	300	228.66	236.47	87.466	84.577	86.022	2.0427
90 s	300	229.41	239.68	87.180	83.445	85.312	2.6414
120 s	300	248.96	234.55	80.334	85.270	82.802	3.4900
150 s	300	230.25	239.55	86.862	83.490	85.176	2.3845
180 s	300	231.71	236.81	86.315	84.456	85.385	1.3144
5 min	300	230.40	228.37	86.806	87.577	87.191	0.5456
10 min	300	222.52	225.83	89.880	88.562	89.221	0.9315
20 min	300	216.76	227.19	92.268	88.032	90.150	2.9952
30 min	300	234.58	222.13	85.259	90.037	87.648	3.3790
40 min	300	215.83	222.03	92.666	90.078	91.372	1.8297
60 min	300	213.97	218.19	93.471	91.663	92.567	1.2783



### Appendix D Determination of Biodiesel Yield using $^1\text{H-NMR}$ Analysis for Strontium Oxide (SrO)

**Table D1**  $^1\text{H-NMR}$  results for Strontium Oxide (SrO) catalyst at catalyst concentration of 1.00 wt% (6:1 methanol/oil molar ratio, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm		Yield (%)		Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	298.61	298.61	66.977	66.977	66.977	0.0000
60 s	300	328.67	268.71	60.851	74.430	67.640	9.6014
90 s	300	309.52	255.23	64.616	78.361	71.488	9.7188
120 s	300	298.91	258.06	66.910	77.501	72.206	7.4894
150 s	300	304.2	248.14	65.746	80.600	73.173	10.5030
180 s	300	280.62	251.47	71.271	79.532	75.402	5.8418
5 min	300	261.33	237.66	76.532	84.154	80.343	5.3897
10 min	300	241.58	232.57	82.788	85.996	84.392	2.2679
20 min	300	229.17	224.04	87.271	89.270	88.271	1.4130
30 min	300	226.08	227.4	88.464	87.951	88.208	0.3631
40 min	300	221.46	219.07	90.310	91.295	90.802	0.6967
60 min	300	221.48	224.4	90.302	89.127	89.714	0.8309

**Table D2**  $^1\text{H-NMR}$  results for Strontium Oxide (SrO) catalyst at catalyst concentration of 3.00 wt% (6:1 methanol/oil molar ratio, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm		Yield (%)		Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	532.22	532.22	37.578	37.578	37.578	0.0003
60 s	300	350.89	351.76	56.998	56.857	56.927	0.0997
90 s	300	298.50	295.08	67.002	67.778	67.390	0.5491
120 s	300	277.62	281.32	72.041	71.093	71.567	0.6700
150 s	300	280.00	256.35	71.429	78.018	74.723	4.6597
180 s	300	268.57	249.7	74.468	80.096	77.282	3.9793



**Table D2 (Cont.)**  $^1\text{H-NMR}$  results for Strontium Oxide (SrO) catalyst at catalyst concentration of 3.00 wt% (6:1 methanol/oil molar ratio, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm		Yield (%)		Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
5 min	300	240.26	227.21	83.243	88.024	85.634	3.3808
10 min	300	227.74	227.8	87.819	87.796	87.808	0.0164
20 min	300	231.90	219.17	86.244	91.253	88.749	3.5421
30 min	300	219.11	228.79	91.278	87.416	89.347	2.7308
40 min	300	222.57	216.61	89.859	92.332	91.096	1.7483
60 min	300	213.33	213.33	93.751	93.751	93.751	0.0003

**Table D3**  $^1\text{H-NMR}$  results for Strontium Oxide (SrO) catalyst at catalyst concentration of 5.00 wt% (6:1 methanol/oil molar ratio, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm		Yield (%)		Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	636.60	340.07	31.417	58.811	45.114	19.3708
60 s	300	330.63	262.39	60.491	76.222	68.356	11.1241
90 s	300	277.32	244.53	72.119	81.790	76.954	6.8382
120 s	300	257.35	247.18	77.715	80.913	79.314	2.2610
150 s	300	232.82	233.42	85.903	85.682	85.793	0.1561
180 s	300	223.95	229.36	89.306	87.199	88.252	1.4900
5 min	300	224.91	216.91	88.924	92.204	90.564	2.3191
10 min	300	211.35	211.45	94.630	94.585	94.607	0.0316
20 min	300	213.88	210.44	93.510	95.039	94.275	1.0809
30 min	300	214.29	208.72	93.331	95.822	94.577	1.7612
40 min	300	215.21	215.21	92.932	92.932	92.932	0.0000
60 min	300	211.47	213.07	94.576	93.866	94.221	0.5022

**Table D4**  $^1\text{H-NMR}$  results for Strontium Oxide (SrO) catalyst at methanol to oil molar ratio of 4.5:1 (catalyst concentration 5.00 wt%, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	379.54	284.51	52.695	70.296	61.496	12.4457
60 s	300, 5.19	314.86	5.09	63.520	67.976	65.748	3.1510
90 s	300	295.87	253.05	67.597	79.036	73.317	8.0882
120 s	300	270.38	247.7	73.970	80.743	77.356	4.7891
150 s	300	258.54	242.6	77.357	82.440	79.899	3.5941
180 s	300	262.61	240.77	76.159	83.067	79.613	4.8849
5 min	300	244.50	232.93	81.800	85.863	83.831	2.8731
10 min	300	231.48	219.52	86.401	91.108	88.754	3.3286
20 min	300	217.31	210.1	92.034	95.193	93.614	2.2333
30 min	300	224.39	210.03	89.131	95.224	92.178	4.3091
40 min	300	216.95	207.13	92.187	96.558	94.372	3.0905
60 min	300	209.76	216.82	93.751	92.242	92.997	1.0667

**Table D5**  $^1\text{H-NMR}$  results for Strontium Oxide (SrO) catalyst at methanol to oil molar ratio of 12:1 (catalyst concentration 5.00 wt%, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	231.68	230.82	86.326	86.648	86.487	0.2274
60 s	300	233.53	229.49	85.642	87.150	86.396	1.0661
90 s	300	226.75	235.71	88.203	84.850	86.526	2.3708
120 s	300	228.84	228.31	87.397	87.600	87.499	0.1435
150 s	300	225.89	222.29	88.539	89.973	89.256	1.0139
180 s	300	223.87	217.66	89.338	91.886	90.612	1.8023
5 min	300	217.05	219.52	92.145	91.108	91.626	0.7331
10 min	300	222.45	219.06	89.908	91.299	90.604	0.9838
20 min	300	225.66	210.59	88.629	94.971	91.800	4.4847
30 min	300	229.19	210.59	87.264	94.971	91.118	5.4500

**Table D5 (Cont.)** <sup>1</sup>H-NMR results for Strontium Oxide (SrO) catalyst at methanol to oil molar ratio of 12:1 (catalyst concentration 5.00 wt%, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
40 min	300	213.87	202.79	93.515	98.624	96.069	3.6129
60 min	300	229.81	207.67	93.751	96.307	95.029	1.8071

**Table D6** <sup>1</sup>H-NMR results for Strontium Oxide (SrO) catalyst at temperature of 70°C (catalyst concentration 5.00 wt%, 6:1 methanol/oil molar ratio, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	246.63	390.77	81.093	51.181	66.137	21.1510
60 s	300	229.28	312.86	87.230	63.926	75.578	16.4779
90 s	300	236.71	268.36	84.492	74.527	79.509	7.0462
120 s	300	232.48	266.28	86.029	75.109	80.569	7.7216
150 s	300	226.07	253.14	88.468	79.008	83.738	6.6896
180 s	300	234.54	250.08	85.273	79.974	82.624	3.7469
5 min	300	228.31	237.44	87.600	84.232	85.916	2.3818
10 min	300	216.81	225.03	92.247	88.877	90.562	2.3827
20 min	300	227.88	219.79	87.765	90.996	89.381	2.2843
30 min	300	219.4	220.22	91.158	90.818	90.988	0.2400
40 min	300	211.17	215.00	94.710	93.023	93.867	1.1930
60 min	300	206.56	216.85	96.824	92.230	94.527	3.2488

**Table D7**  $^1\text{H-NMR}$  results for Strontium Oxide (SrO) catalyst at temperature of  $60^\circ\text{C}$  (catalyst concentration 5.00 wt%, 6:1 methanol/oil molar ratio, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
30 s	300	257.57	258.38	77.649	77.405	77.527	0.1721
60 s	300	257.67	258.20	77.619	77.459	77.539	0.1127
90 s	300	250.93	248.45	79.704	80.499	80.101	0.5626
120 s	300	237.53	238.53	84.200	83.847	84.023	0.2496
150 s	300	234.33	238.55	85.350	83.840	84.595	1.0676
180 s	300	227.30	234.28	87.989	85.368	86.679	1.8537
5 min	300	223.41	226.60	89.522	88.261	88.891	0.8911
10 min	300	222.91	224.04	89.722	89.270	89.496	0.3200
20 min	300	214.71	221.63	93.149	90.240	91.695	2.0566
30 min	300	222.51	216.72	89.884	92.285	91.084	1.6980
40 min	300	222.02	216.37	90.082	92.434	91.258	1.6633
60 min	300	216.03	215.60	93.751	92.764	93.258	0.6976

### Appendix E The Effect of Catalyst Combination on Biodiesel Yield

**Table E1** <sup>1</sup>H-NMR results for catalyst combination (TBD and SrO) in proportion of TBD 30 wt% and SrO 70 wt% based on catalyst concentration 5.00 wt% (methanol to oil molar ratio 6:1, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
2 min	300	295.78	220.98	67.618	90.506	79.062	16.1843
3 min	300	224.84	213.20	88.952	93.809	91.380	3.4341
5 min	300	221.70	220.25	90.212	90.806	90.509	0.4200
10 min	300	220.30	271.61	90.785	73.635	82.210	12.1271
20 min	300	228.29	213.50	87.608	93.677	90.642	4.2914
30 min	300	228.53	221.77	87.516	90.184	88.850	1.8863

**Table E2** <sup>1</sup>H-NMR results for catalyst combination (TBD and SrO) in proportion of TBD 50 wt% and SrO 50 wt% based on catalyst concentration 5.00 wt% (methanol to oil molar ratio 6:1, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
2 min	300	226.30	245.25	88.378	81.549	84.964	4.8287
3 min	300	221.61	228.46	90.249	87.543	88.896	1.9134
5 min	300	217.57	242.60	91.924	82.440	87.182	6.7063
10 min	300	217.63	226.59	91.899	88.265	90.082	2.5696
20 min	300	221.34	243.04	90.359	82.291	86.325	5.7048
30 min	300	220.70	220.70	90.621	90.621	90.621	0.0000

**Table E3**  $^1\text{H-NMR}$  results for catalyst combination (TBD and SrO) in proportion of TBD 70 wt% and SrO 30 wt% based on catalyst concentration 5.00 wt% (methanol to oil molar ratio 6:1, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
2 min	300	225.35	228.46	88.751	87.543	88.147	0.8543
3 min	300	234.69	229.17	85.219	87.271	86.245	1.4514
5 min	300	232.10	232.70	86.170	86.973	86.571	0.5681
10 min	300	222.12	222.24	90.041	89.993	90.017	0.0344
20 min	300	223.74	224.43	89.389	89.115	89.252	0.1943
30 min	300	221.63	221.63	90.240	90.240	90.240	1.4514

**Table E4**  $^1\text{H-NMR}$  results for catalyst combination (TBD and Egg Shell) in proportion of TBD 70 wt% and Egg Shell 30 wt% based on catalyst concentration 2.29 wt% (methanol to oil molar ratio 3.5:1, temperature 60°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
2 min	300	228.07	220.90	87.692	90.539	89.116	2.0127
3 min	300	222.44	221.36	89.912	90.351	90.131	0.3102
5 min	300	217.56	216.04	91.929	93.680	92.804	1.2385
10 min	300	216.61	225.51	92.332	88.688	90.510	2.5767
20 min	300	221.62	224.49	90.245	89.091	89.668	0.8158
30 min	300	221.92	215.89	90.123	92.640	91.381	1.7799

**Table E5**  $^1\text{H-NMR}$  results for catalyst combination (TBD and Lobster Shell) in proportion of TBD 70 wt% and Lobster Shell 30 wt% based on catalyst concentration 2.29 wt% (methanol to oil molar ratio 3.5:1, temperature 60°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
2 min	300	221.25	229.12	90.395	87.291	88.843	2.1956
3 min	300	221.33	232.80	90.363	85.911	88.137	3.1481
5 min	300	222.12	225.52	90.041	89.742	89.892	0.2116
10 min	300	216.05	222.01	92.571	90.086	91.329	1.7573
20 min	300	211.28	211.28	94.661	94.661	94.661	0.0000
30 min	300	-	-	-	-	-	-

**Table E6**  $^1\text{H-NMR}$  results for catalyst combination (SrO and Egg Shell) in proportion of SrO 70 wt% and Egg Shell 30 wt% based on catalyst concentration 5.00 wt% (methanol to oil molar ratio 6:1, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
2 min	300	236.81	269.6	84.456	74.184	79.320	7.2633
3 min	300	228.84	268.77	87.397	74.413	80.905	9.1812
5 min	300	226.33	233.15	88.367	86.805	87.586	1.1039
10 min	300	223.99	226.11	89.290	88.453	88.871	0.5920
20 min	300	221.44	221.06	90.318	90.473	90.396	0.1098
30 min	300	219.74	224.73	91.017	88.996	90.006	1.4290



**Table E7**  $^1\text{H-NMR}$  results for catalyst combination (SrO and Lobster Shell) in proportion of SrO 70 wt% and Lobster Shell 30 wt% based on catalyst concentration 5.00 wt% (methanol to oil molar ratio 6:1, temperature 90°C, mixing rate 800 rpm)

Time	Peak at 3.70 ppm	Peak at 2.30 ppm	Peak at 2.30 ppm	Yield (%)	Yield (%)	Mean Yield (%)	Standard Deviation
		Set 1	Set 2	Set 1	Set 2		
2 min	300	221.25	229.12	90.395	87.291	88.843	2.1956
3 min	300	221.33	232.80	90.363	85.911	88.137	3.1481
5 min	300	222.12	225.52	90.041	89.742	89.892	0.2116
10 min	300	216.05	222.01	92.571	90.086	91.329	1.7573
20 min	300	211.28	211.28	94.661	94.661	94.661	0.0000
30 min	300	-	-	-	-	-	-

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**Proceeding:**

1. Saetang, R., Rirksomboon, T., Romero-zerón, L., and Steward, F.R. (2008, April 23) Evaluation of Heterogeneous Catalyst for Biodiesel Production. Proceedings of the 14<sup>th</sup> PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.

**Presentations:**

1. Saetang, R., Rirksomboon, T., Romero-zerón, L., and Steward, F.R. (2008, April 9-11) Evaluation of Heterogeneous Catalyst for Biodiesel Production. Poster Presentation at the Atlantic Bioenergy Conference, Saint John, New Brunswick, Canada.
2. Saetang, R., Rirksomboon, T., Romero-zerón, L., and Steward, F.R. (2008, April 23) Evaluation of Heterogeneous Catalyst for Biodiesel Production. Poster Presentation at the 14<sup>th</sup> PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.