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APPENDICES

Appendix A Supplemental Materials for Phase Behavior Study

Table A1 Composition of MO/Oc system at surfactant/cosurfact molar ratio of 1:8 and palm oil/diesel ratio of 1:1 (v/v) with ethanol

Alcohols/Oil	Concentration (M)		Composition for Phase Diagram (%)			
	MO	Oc	Alcohol (EtOH alone)	Oil	MO+Oc	Total
0/5	-	-	0	100	0	100
1/5	0.80	0.1000	14.17	70.86	14.97	100
2/5	1.10	0.1375	23.00	57.51	19.49	100
3/5	1.20	0.1500	29.67	49.44	20.89	100
4/5	1.30	0.1625	34.56	43.20	22.24	100
5/5	1.40	0.1750	38.23	38.22	23.55	100
5/4	1.40	0.1750	42.47	33.98	23.55	100
5/3	1.50	0.1875	46.99	28.20	24.81	100
5/2	1.60	0.2000	52.83	21.13	26.04	100
5/1	1.60	0.2000	61.64	12.32	26.04	100
5/0	-	-	100	0	0	100

Table A2 Composition of MO/Oc system at surfactant/cosurfact molar ratio of 1:8 and palm oil/diesel ratio of 1:1 (v/v) with EtOH/BuOH ratio of 1:1 (v/v)

Alcohol/Oil	Concentration (M)		Composition for Phase Diagram (%)			
	MO	Oc	Alcohols (EtOH+BuOH)	Oil	MO+Oc	Total
0/5	-	-	0	100	0	100
1/5	0.16	0.0200	16.10	80.50	3.40	100
2/5	0.16	0.0200	27.60	69.00	3.40	100
3/5	0.24	0.0300	35.62	59.37	5.02	100
4/5	0.28	0.0400	41.87	52.33	5.80	100
5/5	0.28	0.0400	47.10	47.10	5.80	100
5/4	0.28	0.0400	52.33	41.87	5.80	100
5/3	0.28	0.0400	58.87	35.32	5.80	100
5/2	0.40	0.0500	65.65	26.26	8.09	100
5/1	0.40	0.0500	76.59	15.32	8.09	100
5/0	-	-	100	0	0	100

Table A3 Composition of POME/Oc system at surfactant/cosurfact molar ratio of 1:8 and palm oil/diesel ratio of 1:1 (v/v) and ethanol

Alcohols/Oil	Concentration (M)		Composition for Phase Diagram (%)			
	POME	Oc	Alcohols (EtOH alone)	Oil	POME+Oc	Total
0/5	-	-	0	100	0	100
1/5	0.90	0.1125	14.12	70.58	15.30	100
2/5	1.10	0.1375	23.40	58.52	18.08	100
3/5	1.30	0.1625	30.22	50.37	19.41	100
4/5	1.40	0.1750	34.70	43.37	21.93	100
5/5	1.50	0.1875	38.43	38.43	23.14	100
5/4	1.60	0.2000	42.05	33.64	24.31	100
5/3	1.70	0.2125	46.60	27.96	25.44	100
5/2	1.80	0.2250	52.47	20.99	26.54	100
5/1	1.90	0.2375	60.33	12.06	27.61	100
5/0	-	-	100	0	0	100

Table A4 Composition of POME/Oc system at surfactant/cosurfact molar ratio of 1:8 and palm oil/diesel ratio of 1:1 (v/v) with EtOH/BuOH ratio of 1:1 (v/v)

Alcohols/Oil	Concentration (M)		Composition for Phase Diagram (%)			
	POME	Oc	Alcohols (EtOH+BuOH)	Oil	POME+Oc	Total
0/5	-	-	0	100	0	100
1/5	0.20	0.0250	16.02	80.12	3.86	100
2/5	0.25	0.0313	27.21	68.02	4.78	100
3/5	0.35	0.0438	35.04	58.40	6.56	100
4/5	0.35	0.0438	41.53	51.91	6.56	100
5/5	0.35	0.0438	46.72	46.72	6.56	100
5/4	0.40	0.0500	51.43	41.14	7.43	100
5/3	0.40	0.0500	57.86	34.71	7.43	100
5/2	0.45	0.0563	65.51	26.20	8.28	100
5/1	0.45	0.0563	76.43	15.29	8.28	100
5/0	-	-	100	0	0	100

Appendix B Supplemental Materials for Fuel Properties Study

These tables show composition of microemulsion biofuels used in this study in unit of volume percentage. There are three main components in system surfactant phase, oil phase and alcohol phase.

Table B1 Composition of microemulsion biofuels with methyl oleate (MO) as surfactant and 1-octanol as cosurfactant

Sample EtOH:BuOH Ratio	Composition (Vol.%)			
	Surfactant Phase	Oil Phase	Alcohol Phase	
	Surfactant/Cosurfactant (1:8 molar ratio) MO Surfactant	Palm Oil/Diesel (50:50)	Ethanol	Butanol
0:100	-	80.0	-	20.0
30:70	-	80.0	6.0	14.0
50:50	10.0	70.0	10.0	10.0
70:30	14.8	65.2	14.0	6.0
80:20	18.8	61.2	16.0	4.0
90:10	21.4	58.6	18.0	2.0
100:0	24.0	56.0	20.0	-

Table B2 Composition of microemulsion biofuels with palm olein methyl ester (POME) as surfactant and 1-octanol as cosurfactant

Sample EtOH:BuOH Ratio	Composition (Vol.%)			
	Surfactant Phase	Oil Phase	Alcohol Phase	
	Surfactant/Cosurfactant (1:8 molar ratio) POME Surfactant	Palm Oil/Diesel (50:50)	Ethanol	Butanol
0:100	-	80.0	-	20.0
30:70	-	80.0	6.0	14.0
50:50	9.8	70.2	10.0	10.0
70:30	14.8	65.2	14.0	6.0
80:20	17.8	62.2	16.0	4.0
90:10	21.0	59.0	18.0	2.0
100:0	23.0	57.0	20.0	-

Table B3 Composition of RBDPO microemulsion biofuels system with methyl oleate (MO) as surfactant and 1-octanol as cosurfactant

Sample EtOH:BuOH Ratio	Composition (Vol.%)			
	Surfactant Phase	Oil Phase	Alcohol Phase	
	Surfactant/Cosurfactant (1:8 molar ratio) MO Surfactant	RBDPO/Diesel (50:50)	Ethanol	Butanol
0:100	-	80.0	-	20.0
30:70	-	80.0	6.0	14.0
50:50	8.8	71.2	10.0	10.0
70:30	14.2	65.8	14.0	6.0
100:0	23.6	56.4	20.0	-

Table B4 Composition of RBDPO microemulsion biofuels system with palm oil methyl ester (POME) as surfactant and 1-octanol as cosurfactant

Sample EtOH:BuOH Ratio	Composition (Vol.%)			
	Surfactant Phase	Oil Phase	Alcohol Phase	
	Surfactant/Cosurfactant (1:8 molar ratio) POME Surfactant	RBDPO/Diesel (50:50)	Ethanol	Butanol
0:100	-	80.0	-	20.0
30:70	-	80.0	6.0	14.0
50:50	7.8	72.2	10.0	10.0
70:30	13.4	66.6	14.0	6.0
100:0	21.8	58.2	20.0	-

Table B5 Composition of microemulsion biofuels with MO as surfactant and 1-octanol as cosurfactant at palm oil/diesel ratio of 30:70

Sample EtOH:BuOH Ratio	Composition (Vol.%)			
	Surfactant Phase	Oil Phase	Alcohol Phase	
	Surfactant/Cosurfactant (1:8 molar ratio) POME Surfactant	Palm Oil/Diesel (50:50)	Ethanol	Butanol
50:50	10.0	70.0	10.0	10.0
80:20	18.8	61.2	16.0	4.0
90:10	21.4	58.6	18.0	2.0

Table B6 Composition of microemulsion biofuels with POME as surfactant and 1-octanol as cosurfactant at palm oil/diesel ratio of 30:70

Sample EtOH:BuOH Ratio	Composition (Vol.%)			
	Surfactant Phase	Oil Phase	Alcohol Phase	
	Surfactant/Cosurfactant (1:8 molar ratio) POME Surfactant	Palm Oil/Diesel (50:50)	Ethanol	Butanol
50:50	9.8	71.2	10.0	10.0
80:20	17.8	62.2	16.0	4.0
90:10	21.0	59.0	18.0	2.0

Appendix C Supplemental Materials for Viscosity Study

1. Kinematic Viscosity Calculation

The kinematic viscosity of the microemulsion biofuels can be measured by Canon-Fenske type viscometer (ASTM D 445). Kinematic viscosity calculated using Equation C1, which is provided by the manufacturer of the viscometer:

$$\mu = Kt \qquad \text{(C1)}$$

where μ is Kinematic viscosity (cSt)

K is Viscosity constant (K=0.01606 cSt/s at 40 ^{o}C)

t is Time of sample flow in viscometer (second)

Example : The sample kinematic viscosity calculation of methyl oleate/1-octanol in palm oil/diesel blend with ethanol can be shown as follows:

t = 439 sec

K = 0.01606 cSt/s

Therefore;

μ = (0.01606 cSt/s)(439 sec) = 7.05 cSt

2. Raw Data of Kinematic Viscosity in Palm Oil Systems

Table C1 Time and kinematic viscosity of microemulsion biofuels blends at a surfactant/cosurfactant at molar ratio of 1:8 with MO as surfactant and palm oil/diesel 1:1 (v/v) with 20 vol.% of alcohols

Sample (EtOH:BuOH)	Time (s)			Viscosity (cSt)			
	#1	#2	#3	#1	#2	#3	Average
0:100	497	499	489	7.982	8.014	7.853	7.950
30:70	478	471	474	7.677	7.564	7.612	7.618
50:50	439	432	440	7.050	6.938	7.066	7.018
30:70	397	391	397	6.376	6.279	6.376	6.344
20:80	365	372	367	5.862	5.974	5.894	5.910
10:90	362	371	359	5.814	5.958	5.766	5.846
0:100	354	352	356	5.685	5.653	5.717	5.685

Table C2 Time and kinematic viscosity of microemulsion biofuels blends at a surfactant/cosurfactant at molar ratio of 1:8 with POME as surfactant and palm oil/diesel 1:1 (v/v) with 20 vol.% of alcohols

Sample (EtOH:BuOH)	Time (s)			Viscosity (cSt)			
	#1	#2	#3	#1	#2	#3	Average
0:100	497	499	489	7.982	8.014	7.853	7.950
30:70	478	471	474	7.677	7.564	7.612	7.618
50:50	396	401	395	6.360	6.440	6.344	6.381
30:70	395	392	385	6.344	6.296	6.183	6.274
20:80	372	382	382	5.974	6.135	6.135	6.081
10:90	365	371	367	5.862	5.958	5.894	5.905
0:100	347	350	343	5.573	5.621	5.509	5.567

3. Raw Data of Kinematic Viscosity in RBDPO Systems

Table C3 Time and kinematic viscosity of microemulsion biofuels blends at a surfactant/cosurfactant at molar ratio of 1:8 with MO as surfactant and RBDPO/diesel 1:1 (v/v) with 20 vol.% of alcohols

Sample (EtOH:BuOH)	Time (s)			Viscosity (cSt)			
	#1	#2	#3	#1	#2	#3	Average
0:100	485	482	477	7.789	7.741	7.661	7.730
30:70	462	466	459	7.420	7.484	7.372	7.425
50:50	430	427	435	6.906	6.858	6.986	6.917
30:70	388	380	385	6.231	6.103	6.183	6.172
0:100	349	348	352	5.605	5.589	5.653	5.616

Table C4 Time and kinematic viscosity of microemulsion biofuels blends at a surfactant/cosurfactant at molar ratio of 1:8 with POME as surfactant and RBDPO/diesel 1:1 (v/v) with 20 vol.% of alcohols

Sample (EtOH:BuOH)	Time (s)			Viscosity (cSt)			
	#1	#2	#3	#1	#2	#3	Average
0:100	485	482	477	7.789	7.741	7.661	7.730
30:70	462	466	459	7.420	7.484	7.372	7.425
50:50	390	392	399	6.263	6.296	6.408	6.322
30:70	385	369	377	6.183	5.926	6.055	6.055
0:100	344	336	329	5.525	5.396	5.284	5.402

4. Raw Data of Kinematic Viscosity in Palm Oil System (Palm Oil:Diesel = 30:70)

Table C5 Time and kinematic viscosity of microemulsion biofuels blends at a surfactant/cosurfactant at molar ratio of 1:8 with MO and POME as surfactants and palm oil/diesel 30:70 (v/v) with 20 vol.% of alcohols

Sample (EtOH:BuOH)		Time (s)			Viscosity (cSt)			
		#1	#2	#3	#1	#2	#3	Average
50:50	MO	304	304	312	4.882	4.882	5.011	4.925
	POME	299	297	300	4.802	4.770	4.818	4.797
80:20	MO	283	287	276	4.545	4.609	4.433	4.529
	POME	274	285	279	4.400	4.577	4.481	4.486
90:10	MO	271	278	267	4.352	4.465	4.288	4.368
	POME	263	281	269	4.224	4.513	4.320	4.352

Appendix D Supplemental Materials for Droplet Size Study

1. Raw Data of Droplet Size in MO Systems

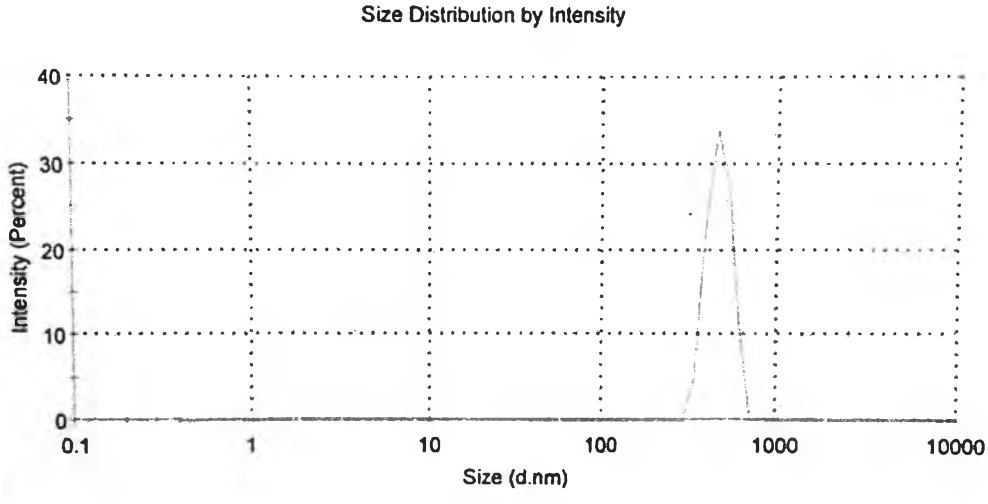

Figure D1 Droplet size of palm oil/diesel blend at ratio 1:1 (v/v), MO as surfactant and 1-octanol mixed at a molar ratio of 1:8 and EtOH/BuOH ratio of 0:100.

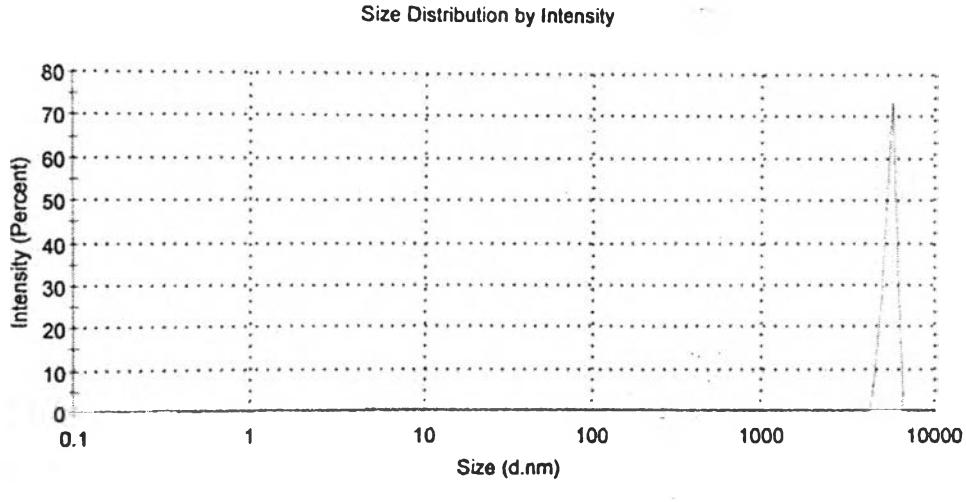

Figure D2 Droplet size of palm oil/diesel blend at ratio 1:1 (v/v), MO as surfactant and 1-octanol mixed at a molar ratio of 1:8 and EtOH/BuOH ratio of 50:50.

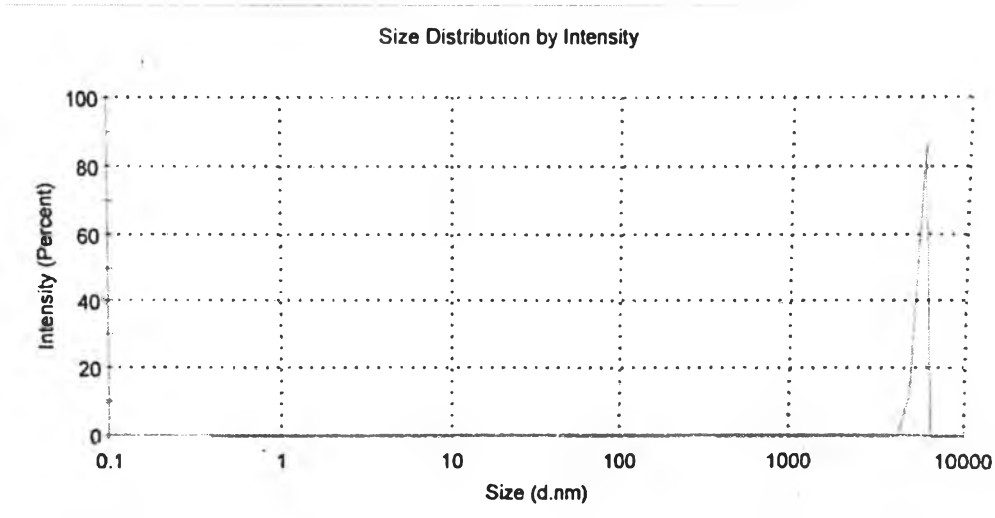

Figure D3 Droplet size of palm oil/diesel blend at ratio 1:1 (v/v), MO as surfactant and 1-octanol mixed at a molar ratio of 1:8 and EtOH/BuOH ratio of 100:0.

2. Raw Data of Droplet Size in POME Systems

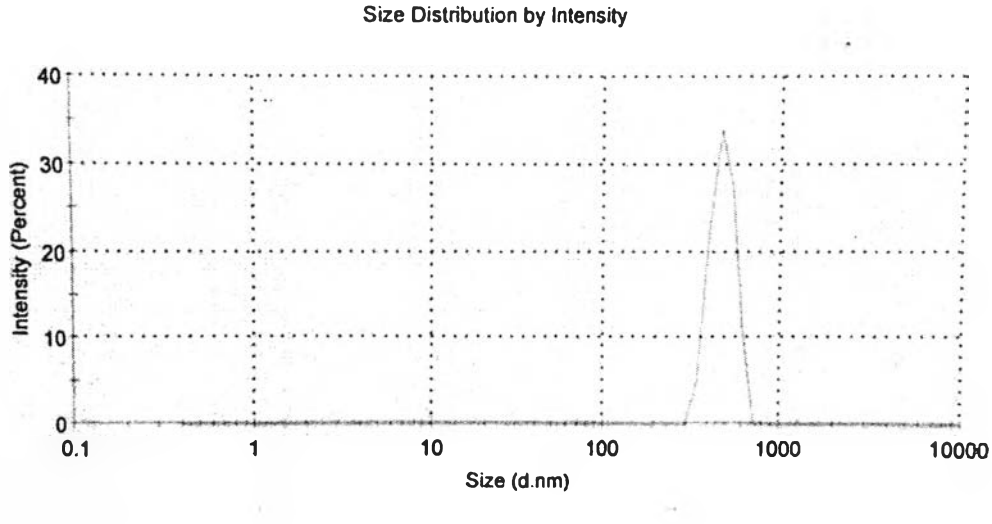

Figure D4 Droplet size of palm oil/diesel blend at ratio 1:1 (v/v), POME as surfactant and 1-octanol mixed at a molar ratio of 1:8 and EtOH/BuOH ratio of 0:100.

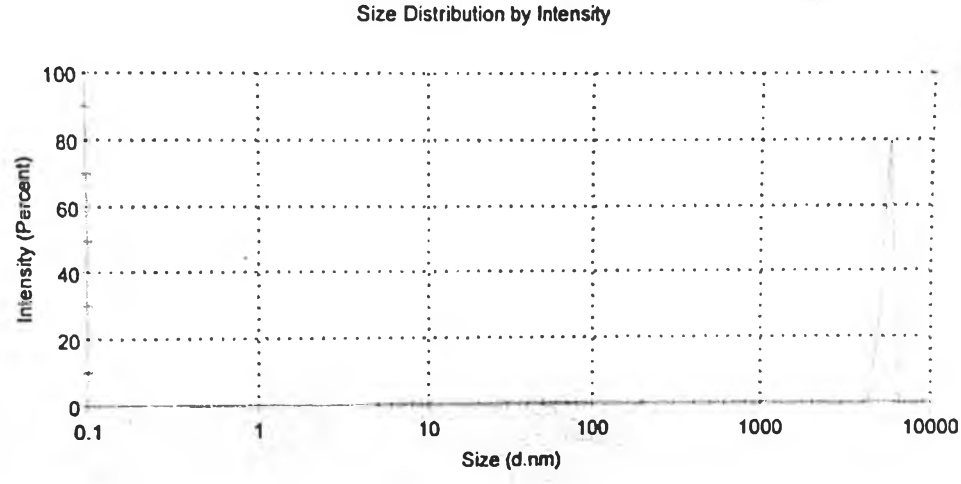

Figure D5 Droplet size of palm oil/diesel blend at ratio 1:1 (v/v), POME as surfactant and 1-octanol mixed at a molar ratio of 1:8 and EtOH/BuOH ratio of 50:50.

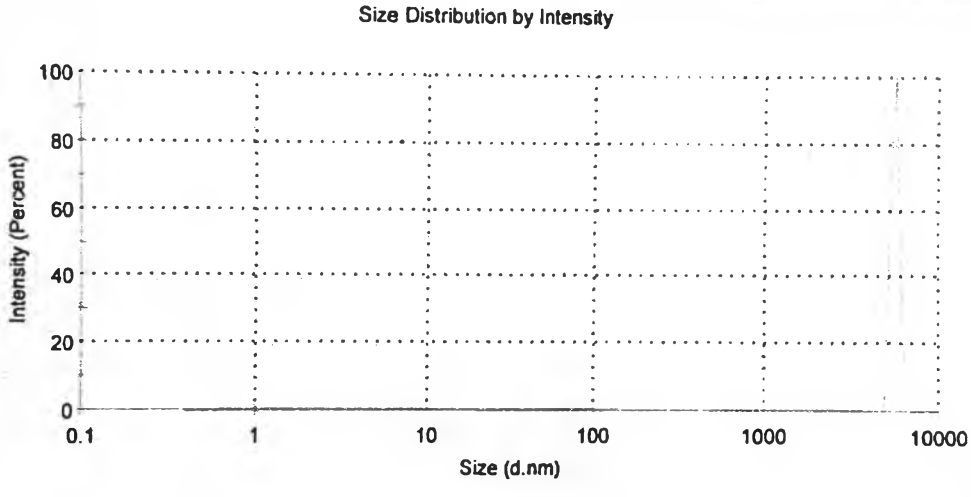

Figure D6 Droplet size of palm oil/diesel blend at ratio 1:1 (v/v), POME as surfactant and 1-octanol mixed at a molar ratio of 1:8 and EtOH/BuOH ratio of 100:0.

Appendix E Supplemental Materials for Density Determination

Table E1 Density of MO system

Sample (EtOH:BuOH)	Density (g/mL) at 25°C			
	#1	#2	#3	Average
0:100	0.856	0.851	0.850	0.852
30:70	0.850	0.848	0.856	0.851
50:50	0.846	0.849	0.850	0.848
30:70	0.839	0.840	0.846	0.842
100:0	0.832	0.830	0.838	0.833

Table E2 Density of POME system

Sample (EtOH:BuOH)	Density (g/mL) at 25°C			
	#1	#2	#3	Average
0:100	0.856	0.851	0.850	0.852
30:70	0.850	0.848	0.856	0.851
50:50	0.846	0.840	0.850	0.845
30:70	0.838	0.845	0.838	0.840
100:0	0.830	0.820	0.838	0.829

Appendix F HLB Calculation of Nonionic Surfactants

HLB calculation for nonionic products is obtained with the Griffin formula (Equation F1):

$$HLB = 20 \times \frac{MW_H}{MW_H + MW_L} = 20 \times \frac{MW_H}{MW} \qquad (F1)$$

Where MW_H = Molecular weight of hydrophilic part

MW_L = Molecular weight of hydrophobic part

MW = Molecular weight of surfactant

1. HLB Calculation of Methyl Oleate (MO)

MW_H = 59.04

MW = 296.5

$$HLB = 20 \times \frac{MW_H}{MW}$$

$$= 20 \times \frac{59.04}{296.5}$$

$$= 3.98$$

2. HLB Calculation of Palm Oil Methyl Ester (POME)

HLB_{AVG} calculation of mixed product is obtained by Equation F2:

$$HLB_{AVG} = \%wt_1 \times HLB_1 + \%wt_2 \times HLB_2 + \%wt_3 \times HLB_3 + \cdots \qquad (F2)$$

Table F1 HLB calculation of POME

Fatty Acid Composition	Carbon Number	Composition (%)	MW_H	MW	HLB	%×HLB
Lauric acid	C12:0	0.1	59.04	214.35	5.51	0.0055
Myristic acid	C14:0	0.9	59.04	242.40	4.87	0.0438
Palmitic acid	C16:0	45.6	59.04	270.46	4.37	1.9908
Palmitoleic acid	C16:1	0.4	59.04	268.44	4.40	0.0176
Stearic acid	C18:0	3.8	59.04	298.51	3.96	0.1503
Oleic acid	C18:1	38.6	59.04	296.50	3.98	1.5372
Linoleic acid	C18:2	10.5	59.04	294.48	4.01	0.4210
Linolenic acid	C18:3	0.1	59.04	292.46	4.04	0.0040
		1.0	HLB average			4.17

Appendix G Supplemental Materials for Heat of Combustion

Table G1 Heat of combustion of POME system

Sample (EtOH:BuOH)	Heat of Combustion (MJ/kg)		
	#1	#2	Average
50:50	39.78	39.68	39.73
70:30	39.22	39.22	39.22
90:10	38.79	38.99	38.89
100:0	38.58	38.57	38.58

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