High Intensity Ultrasound Assisted Transesterification of Espresso Coffee Oil Methyl Ester: Optimization through Response Surface Methodology Approach

Krit Somnuk, Pichai Eawlex, Jarernporn Thawornprasert, and Gumpon Prateepchaikul

Abstract—High intensity ultrasound was used to accelerate the ester conversion of biodiesel production from espresso coffee oil (ECO) with a base-catalyzed transesterification. The ester conversion from ECO biodiesel production was optimized through three parameters: methanol, potassium hydroxide, and ultrasonic reaction time with a response surface methodology (RSM). After ECO has gone through the ultrasonic homogenizer (1000W ultrasonic power, 18 kHz ultrasonic frequency) for the biodiesel production. The maximum methyl ester of 96.385 wt.% was achieved under an optimal condition: 30.8 vol.% methanol, 16.6 gKOH/L, and 72 sec ultrasonic reaction time.

Index Terms—Coffee oil, high intensity ultrasound, biodiesel, methyl ester, response surface methodology.

I. INTRODUCTION

Organic wastes from brewed coffee, spent coffee grounds (SCG) having an oil content of approximately 7 to 15 wt.%, depending on coffee varieties [1], [2] and have promising feedstock of biodiesel production [3]-[5]. The International Coffee Organization (ICO) has reported that a world coffee consumption is approximately equal to 9.47 million tonnes in 2016/17 [ICO, 2018]. Therefore, an approximately 1.37 billion liters of biodiesel from coffee oil could be added to the world fuel supply [1], [6]. Regarding the instant coffee powder preparation with hot water, almost half of the world coffee consumption was processed for instant coffee [7]. After coffee extraction for instant coffee powder, 2 kg of SCG per one kg of instant coffee powder obtained [8]. Regarding the espresso brewing method from fresh coffee beans, the hot water under pressure through a bed of finely ground coffee beans. The hot steam from water pressure is distributed in the roasted coffee grounds [9]. In Thailand, the fresh coffee beans were used to produce instant coffee, roasted and ground coffee, and canned coffee [10], [11].

Regarding coffee oil extraction with solvent, a simple extraction process of SCG oil can be extracted with *n*-hexane using a vigorous stirrer, and defatted organic wastes was separated by gravity method. These organic wastes were removed and the miscella was then distilled by simple

distillation method to obtain the coffee oil [10]. Moreover, the soxhlet extraction method has more effective than the simple extraction process. Banerjee *et al.* (2013) studied the coffee oil extracted from SCG could be used for producing the biodiesel using a commercial preparations of lipases. For the coffee oil extraction procedure, 6% yield of coffee oil was achieved by a simple hexane extraction under reflux conditions, whereas, 14% oil yield was extracted by the soxhlet extraction [12]. Somnuk *et al.* (2017) optimized the two parameters (extraction time and ratio of dried spent coffee grounds (DSCG)-to-solvent) to investigate the highest yield of SCG oil in the batch mode. The results showed that the experimental yields achieved were 14.7 wt.% (using hexane), 13.1 wt.% (using anhydrous ethanol), 11.8 wt.% (using hydrous ethanol), and 7.5 wt.% (using methanol) [10].

Regarding the methyl ester production using ultrasound, the ultrasonic irradiation assisted the chemical and physical effects from the collapse of the cavitation bubbles [13]–[17]. A low frequency ultrasonic irradiation can be used to produce biodiesel using the transesterification reaction [18]. S æz-Bastante et al. (2015) studied the ultrasound-assisted biodiesel production from Camelina sativa oil. The ultrasound irradiation was used to accelerate the esterification reaction, and the cavitation bubbles were then generated in the sonoreactor. They concluded that the conventional transesterification with mechanical stirrer is higher requirements on the catalyst concentration and the reaction time than ultrasound. Although methyl ester content from conventional results met EN 14103 standard, however, the yields of methyl esters were lower than ultrasound-assisted transesterification. Moreover, the ultrasound required a lower energy consumption. temperature, catalyst and reaction time [16].

The use of non-edible vegetable oil for biodiesel production, the extracted oil from SCG will lessen competition with food resources for biodiesel production such as soybean, rapeseed, coconut oil, and crude palm oil [19], [20]. To the best of the authors' knowledge, a few researcher has directly focused on the optimization of methyl ester production from espresso coffee oil extraction using a high intensity ultrasound. The objective of this study was to demonstrate optimization of methyl ester purity from coffee oil using response surface methodology (RSM). Three parameters were methanol content, KOH loading, and ultrasonic reaction time were investigated. Fig. 1 shows the diagram of espresso coffee oil (ECO) extraction and biodiesel production from ECO using high intensity ultrasound.

Manuscript received January 20, 2020; revised March 31, 2020. This work was supported by the Energy Policy and Planning Office of Thailand (EPPO), and by Prince of Songkla University, Grant No. ENG570896S.

The authors are with the Department of Mechanical Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla, Thailand (e-mail: krit.s@psu.ac.th, pichai.eawlex@gmail.com, thawornprasert.j@gmail.com, gumpon.p@psu.ac.th).

II. MATERIALS AND METHODS

A. Materials

The espresso coffee oil (ECO) obtained from oil extraction process in the spent coffee grounds (SCG). The freshly brewed Arabica SCG form espresso brewing was used as the raw material of oil extraction, which the high moisture content in SCG was removed throughout drying process. The dried spent coffee grounds (DSCG) will go through the oil extraction process with hexane. The ECO was used as the feedstock for biodiesel production using a high intensity ultrasound. Commercial grade reactants were 99% purity of methanol (MeOH) and 95% purity of KOH, for transesterification reaction. Analytical grade reactants: a hexane, a diethyl ether, and a formic acid, were used to analyse by the thin layer chromatograph with flame ionization detection (TLC/FID), as described in Section of analysis methods.

B. Biodiesel Production from ECO

Generally, the important problem of biodiesel production is the FFA content in the feedstock. The FFA content should be reduced to less than 1 wt.% FFA, when the transesterification reaction was directly reacted to convert the total glycerides to biodiesel [21]. If the FFA content in oil is over 1 wt.%, saponification reaction will occur during the base-catalyst reacts with FFA [21]. However, ECO has less than 1 wt.% of FFA content, thus, it can be catalyzed with the base-catalyzed direct transesterification reaction, as in (1) [22].

Triglycerides + Alcohol
$$\leftarrow \frac{\text{Base catalyst}}{\text{Glycerol} + \text{Ester (1)}}$$

C. Use of High Intensity Ultrasound in the Biodiesel Production from ECO

The equipment of biodiesel production from ECO was employed with base-catalyzed transesterification using high intensity ultrasound. The 1000W ultrasonic homogenizer was operated at 18 kHz frequency in the batch reactor. A small cylindrical vessel reactor made with 316L stainless steel having dimensions of 34 mm ID, 150 mm height and 8 mm thickness. The 316L stainless steel circular horn tip of ultrasonic probe has the surface area of approximately 615.75 mm². The ultrasound was directly sonicated at horn tip into the mixtures: ECO and potassium methoxide to rapidly convert the glycerides in SCG oil to ester. The high surface power density ($I_{\rm US}$, W/mm²) at horn tip is defined as the ultrasonic power $(P_{\rm US}, W)$ divided by the surface area of horn tip (A_c , mm²), as expressed in (2) [21]. Acoustic energy density (AED, W/mL) is defined as the ultrasonic power divided by the total volume of the mixture (V_{total} , mL), as expressed in (3) [21]. The continuous mode of ultrasound was transmitted into the mixtures. The ultrasonic power of 1000W was applied into a 50 mL total volume of mixture. The details of positions of horn and reactor after immersion of the ultrasonic probe were described in the previous paper of [23].

$$I_{\rm US} = P_{\rm US} / A_{\rm c} \tag{2}$$

$$AED = P_{\rm US} / V_{\rm total} \tag{3}$$

where $I_{\rm US}$ is a high surface power density (W/mm²), $P_{\rm US}$ is an ultrasonic power (W), $A_{\rm c}$ is a surface area of horn tip (mm²); AED is an acoustic energy density (W/mL), and $V_{\rm total}$ is a total volume of the mixture (mL).

D. Experimental Procedure

In the experimental procedure, ECO can be used at room temperature (30 °C). The potassium hydroxide (KOH) was dissolved with methanol, is known as a potassium methoxide (CH₃OK). In the sonochemical reaction, ECO was poured into the ultrasonic reactor. Subsequently, the CH₃OK was then loaded into the ultrasonic reactor and the ultrasonic homogenizer was then immediately turned on to accelerate a sonochemical transesterification reaction. As shown in Table I, the three parameters: methanol (21.6 to 38.4 vol.%), KOH (6.6 to 23.4 g/L of oil), and ultrasonic reaction time (10 to 110 seconds), were investigated and optimized with response surface methodology (RSM) approach.



Fig. 1. Diagram of espresso coffee oil (ECO) extraction and biodiesel production using high intensity ultrasound.

Indonondont voriable	Coded level					
independent variable	-1.682	-1	0	+1	+1.682	
Methanol (vol.%)	21.6	25	30	35	38.4	
KOH (gKOH/L of oil)	6.6	10	15	20	23.4	
Ultrasonic reaction time (sec)	10	30	60	90	110	

E. Analysis Methods

The thin layer chromatograph with flame ionization detection (TLC/FID) (IATROSCAN MK-65; Mishubishi Kagahu Latron Inc., Tokyo, Japan) was used to analyze the conversions of methyl ester (ME), triglyceride (TG), diglyceride (DG), monoglyceride (MG), and free fatty acid (FFA) in the ECO and biodiesel. Analysis used the following chemical standards: tripalmitin, palmitic acid, methyl palmitate (sourced from Nacala Tesque); 1,3-distearin; DL palmitin (mono palmitin) (sourced from Sigma Aldrich); and 1,2-di-stearin 99%, (sourced from Research Plus).

F. Experimental Design for Biodiesel Production

Response surface methodology (RSM), with 5-level and 3-factor central composite design (CCD), was used to optimize the high intensity ultrasound assisted methyl ester production from ECO in a batch mode. Multiple regression analysis was employed to derive a second-order polynomial equation to predict the purity of methyl ester after the ultrasonic transesterification with the response surface model. A general second-order polynomial equation is expressed as shown in (4) [24]. The three independent variables: methanol (*M*), KOH (*K*), and ultrasonic reaction time (*T*) were studied to evaluate the purity of methyl ester (*ME*). Table II shows the five-code-level of varying ranges of three independent variables, which are coded as -1.682, -1, 0, +1, and +1.682.

$$ME = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k} \sum_{j=i+1}^{k} \beta_{ij} x_i x_j + \varepsilon$$
(4)

where *ME* (purity of *ME*, wt.%) is methyl ester or dependent variable; x_i and x_j are the uncoded independent variables (methanol, vol.%; KOH, g/L of oil; ultrasonic reaction time, sec); β_0 , β_i , β_{ii} , α_{ii} , β_{ij} are the intercept, linear, quadratic and interaction constant coefficients, respectively; k is the number of variables, and ε is the error.

TABLE II: EXPERIMENTAL DESIGN MATRIX AND METHYL ESTER RESULTS

Run	М	K	Т	ME
	(vol.%)	(g/L of oil)	(sec)	(wt.%)
1	30	15	60	93.660
2	30	15	60	94.474
3	30	15	60	94.322
4	30	15	60	93.879
5	38.4	15	60	70.481
6	21.6	15	60	65.227
7	25	10	30	52.451
8	35	10	30	60.249
9	25	20	30	90.448
10	35	20	30	92.602
11	35	10	90	84.300
12	25	10	90	80.896
13	35	20	90	85.702
14	25	20	90	75.496
15	30	6.6	60	57.682
16	30	23.4	60	81.903
17	30	15	10	50.831
18	30	15	110	93.408

Note: M is methanol, K is KOH, T is ultrasonic reaction time, and ME is methyl ester.

III. RESULTS AND DISCUSSIONS

A. Experimental Results

Fig. 2 shows the ECO, the crude biodiesel, and the purified biodiesel. Eighteen tests were carried out in the analyzing conditions to convert the glycerides to ester, and to optimize the purity of ester. Table II shows the experimental design matrix and the results of these tests. It was found that these mixtures were catalyzed using the sonochemical base-catalyzed transesterification, the ranges of methyl ester were achieved between 50.831 wt.% and 94.474 wt.%.

B. Response Surface Models of Results and Statistical Analysis

According to Table III, the regression analyses were performed to fit the response model with data from eighteen experimental results using the multiple regression analysis tool in Microsoft Excel add-in tool. The results showed that the relationships between the purity of methyl ester and the independent variables were obtained in the general formula of a quadratic model. The model of the three responses is expressed in (5), to predict the purity of methyl ester production from ECO. The goodness of fit of this predicted model is defined by the coefficient of determination (R^2), the adjusted coefficient of determination (R^2), and *p*-value of the response models, as listed in Table IV.



Fig. 2. Products and by-product of biodiesel production process. (a) coffee oil; (b) crude biodiesel; [a top layer is the crude biodiesel; a bottom layer is the glycerol]; (c) purified biodiesel from coffee oil.

TABLE III: COEFFICIENT VALUES AND P-VALUE OF STATISTICAL ANALYSIS

Coefficient	Value	<i>p</i> -value
β_0	-358.28	0.00175
β_1	17.89	0.00561
β_2	13.17	0.000801
β_3	1.946	0.00059
β_4	-0.290	0.00644
B5	-0.263	0.01113
Be	-0.06196	0.00580
β_7	-0.00639	0.02165

Note: $R^2 = 0.862$, $R^2_{adjusted} = 0.765$

$$ME = \beta_0 + \beta_1 M + \beta_2 K + \beta_3 T + \beta_4 M^2 + \beta_5 K^2 + \beta_6 KT + \beta_7 T^2$$
(5)

where *M* is methanol; *K* is potassium hydroxide; *T* is ultrasonic reaction time; and β is coefficient value.

C. Contour Plots

Fig. 3 shows the relationships between the dependent and independent variables. Three independent variables: methanol, KOH, and ultrasonic reaction time were optimized using RSM, which is presented by the two-dimensional contour plots. The effects of methanol and KOH, ultrasonic reaction time and methanol, ultrasonic reaction time and KOH, on the purity of methyl ester, are shown in Fig. 3a, 3b, and 3c, respectively.



Fig. 3. Contour plots of (a) methanol and KOH; (b) ultrasonic reaction time and methanol; (c) ultrasonic reaction time and KOH, on the methyl ester.

D. Statistical Analysis and Analysis of Variance

The statistical analysis data and analysis of variance (ANOVA) of each predicted model are shown in Table III

and Table IV, respectively. The lowest *p*-values of 0.00059 occurred in the term $\beta_3 T$. Thus, the ultrasonic reaction time was strongly influenced for producing methyl ester from ECO using a probe-type ultrasound. The second and third lowest *p*-values of 0.000801 and 0.00561 appeared in the terms $\beta_2 K$ (KOH concentration) and $\beta_1 M$ (methanol content), respectively.

TABLE IV: ANOVA FOR PREDICTED MODEL					
Source	SS	MS	F_0	$F_{\rm signif}$	<i>p</i> -value
Regression	3530.8	504.40	8.904	0.00131	7
Residual	566.48	56.65			10
LOF Error	566.05	80.86	563.4595	0.000114	7
Pure Error	0.431	0.144			3
Total	4097.3				17

E. Optimization and Verification of Biodiesel Production from ECO

As mentioned in the previous section, the two-dimensional contour plots (Fig. 3) were also plotted for the purity of methyl ester from the biodiesel production process. The optimal condition of methyl ester was solved by Excel solver from Microsoft Excel add-in tool, to calculate the optimal condition. The 96.551 wt.% of maximum methyl ester from model was obtained under the optimum condition was 30.8 vol.% methanol, 16.6 gKOH/L of oil, 72 sec ultrasonic reaction time. This optimum conditions for methyl ester obtained were employed to verify the model purity results with actual experiment. The 96.385 wt.% ester and 3.615 wt.% monoglyceride in biodiesel from the actual experimental results were achieved. Table V shows the physical properties and composition of ECO and biodiesel at optimal condition.

 TABLE V: COMPOSITIONS OF ECO AND BIODIESEL AT OPTIMAL CONDITION

 Property
 Espresso coffee oil
 Biodiesel

Free fatty acid (wt.%)	0.412	-
Triglyceride (wt.%)	81.156	-
Diglyceride (wt.%)	5.926	-
Monoglyceride (wt.%)	11.428	3.615
Ester (wt.%)	1.078	96.385
Higher heating value, HHV (MJ/kg)	38.38	-

F. Biomass Pellet from DFSCG

Approximately 23.1 MJ/kg of higher heating value (HHV) from DSCG, and 20.4 MJ/kg from defatted spent coffee grounds (DFSCG) were derived [10]. For preliminary production of coffee pellets, they can be formed using flat and die pellet machine. The dimensions of coffee pellets from DFSCG: 6-7 mm of diameter, and 30-40 mm length were achieved using the flat die pellet press, as shown in Fig. 4.



Fig. 4. Coffee pellets from defatted spent coffee grounds.

IV. CONCLUSIONS

The high–intensity ultrasound for producing methyl ester from espresso coffee oil (ECO) was tested with actual experiment. Methanol in the presence of KOH loading as catalyst, and ultrasonic reaction time for the methyl ester production were optimized through response surface methodology approach. The maximum methyl ester of 96.385 wt.% was achieved under the optimal condition: 30.8 vol.% methanol, 16.6 gKOH/L, and 72 sec ultrasonic reaction time.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The authors conducted the research, data analysis, and prepared the manuscript; all authors had approved the final version.

REFERENCES

- R. W. Jenkins, N. E. Stageman, C. M. Fortune, and C. J. Chuck, "Effect of the type of bean, processing, and geographical location on the biodiesel produced from waste coffee grounds," *Energy. Fuels*, vol. 28, no. 2, pp. 1166-1174, January 2014.
- [2] S. Obruca, S. Petrik, P. Benesova, Z. Svoboda, L. Eremka, and I. Marova, "Utilization of oil extracted from spent coffee grounds for sustainable production of polyhydroxyalkanoates," *Appl. Microbiol. Biotechnol.*, vol. 98, no. 13, pp. 5883-5890, July 2014.
- [3] D. R. Vardon, B. R. Moser, W. Zheng, K. Witkin, R. L. Evangelista, T. J. Strathmann, K. Rajagopalan, and B. K. Sharma, "Complete utilization of spent coffee grounds to produce biodiesel, bio-oil, and biochar," ACS. Sustain. Chem. Eng., vol. 1, no. 10, pp. 1286-1294, August 2013.
- [4] Z. Al-Hamamre, S. Foerster, F. Hartmann, M. Kröger, and M. Kaltschmitt, "Oil extracted from spent coffee grounds as a renewable source for fatty acid methyl ester manufacturing," *Fuel*, vol. 96, pp. 70-76, June 2012.
- [5] N. S. Caetano, V. F. M. Silva, and T. M. Mata, "Valorization of coffee grounds for biodiesel production," *Chem. Eng. Trans.*, vol. 26, pp. 267-272, 2012.
- [6] R. Campos-Vega, G. Loarca-Piña, H. Vergara-Castañeda, and B. D. Oomah, "Spent coffee grounds: A review on current research and future prospects," *Trends. Food. Sci. Technol.*, vol. 45, no. 1, pp. 24-36, September 2015.
- [7] S. I. Mussatto, E. M. S. Machado, S. Martins, and J. A. Teixeira, "Production, composition, and application of coffee and its industrial residues," *Food. Bioprocess. Technol.*, vol. 4, pp. 661-672, March 2011.
- [8] R. A. Pfluger, Solid Wastes: Origin, Collection, Processing, and Disposal, Toronto: John Wiley & Sons Inc, 1975.
- [9] E. Illy and L. Navarini, "Neglected food bubbles: The espresso coffee foam," *Food. Biophys.*, vol. 6, pp. 335-348, March 2011.
- [10] K. Somnuk, P. Eawlex, and G. Prateepchaikul, "Optimization of coffee oil extraction from spent coffee grounds using four solvents and prototype-scale extraction using circulation process," *Agriculture and Natural Resources*, vol. 51, no. 3, pp. 181-189, June 2017.
- [11] K. Pongsiri and A. C. Consumption, "Market feasibility for new brand coffee house: The case study of Thailand," *Int. J. Soc. Behav. Educ. Econ. Manag. Eng.*, vol. 7, no. 8, pp. 2414-2417, 2013.
- [12] A. Banerjee, V. Singh, K. Solanki, J. Mukherjee, and M. N. Gupta, "Combi-protein coated microcrystals of lipases for production of biodiesel from oil from spent coffee grounds," *Sustain. Chem. Process.*, vol. 1, no. 14, pp. 1-9, August 2013.
- [13] K. Somnuk, P. Smithmaitrie, and G. Prateepchaikul, "Two-stage continuous process of methyl ester from high free fatty acid mixed crude palm oil using static mixer coupled with high-intensity of ultrasound," *Energy. Convers. Manag.*, vol. 75, pp. 302-310, November 2013.
- [14] M. V. P. Rocha, L. J. B. L. Matos, L. P. D. Lima, P. M. D. S. Figueiredo, I. L. Lucena, F. A. N. Fernandes, and L. R. B. Gonçalves,

"Ultrasound-assisted production of biodiesel and ethanol from spent coffee grounds," *Bioresour. Technol.*, vol. 167, pp. 343-348, September 2014.

- [15] W. W. S. Ho, H. K. Ng, S. Gan, and W. L. Chan, "Ultrasound-assisted transesterification of refined and crude palm oils using heterogeneous palm oil mill fly ash supported calcium oxide catalyst," *Energy Sci. Eng.*, vol. 3, pp. 257-269, February 2015.
- [16] J. Sáz-Bastante, C. Ortega-Román, S. Pinzi, F. R. Lara-Raya, D. E. Leiva-Candia, and M. P. Dorado, "Ultrasound-assisted biodiesel production from camelina sativa oil," *Bioresour. Technol.*, vol. 185, pp. 116-124, June 2015.
- [17] K. S. Ojha, T. J. Mason, C. P. O'Donnell, J. P. Kerry, and B. K. Tiwari, "Ultrasound technology for food fermentation applications," *Ultrason. Sonochem.*, vol. 34, pp. 410-417, January 2017.
- [18] I. Worapun, K. Pianthong, and P. Thaiyasuit, "Two-step biodiesel production from crude Jatropha curcas L. oil using ultrasonic irradiation assisted," *J Oleo Sci.*, vol. 61, no. 4, pp. 165-172, October 2012.
- [19] X. Li, V. Strezov, and T. Kan, "Energy recovery potential analysis of spent coffee grounds pyrolysis products," *J. Anal. Appl. Pyrolysis.*, vol. 110, pp. 79-87, November 2014.
- [20] N. S. Caetano, V. F. M. Silva, A. C. Melo, A. A. Martins, and T. M. Mata, "Spent coffee grounds for biodiesel production and other applications," *Clean. Technol. Environ.*, vol. 16, no. 7, pp. 1423-1430, October 2014.
- [21] K. Somnuk, P. Smithmaitrie, and G. Prateepchaikul, "Optimization of continuous acid-catalyzed esterification for free fatty acids reduction in mixed crude palm oil using static mixer coupled with high-intensity ultrasonic irradiation," *Energy. Convers. Manag.*, vol. 68, pp. 193-199, Apirl 2013.
- [22] K. Somnuk, N. Soysuwan, and G. Prateepchaikul. (2017). Optimizing three-step production of methyl ester from palm fatty acid distillate: A response surface methodology approach. *Biofuels*. [Online]. Available: https://doi.org/10.1080/17597269.2017.1369630
- [23] K. Somnuk, T. Prasit, and G. Prateepchaikul, "Effects of mixing technologies on continuous methyl ester production: Comparison of using plug flow, static mixer, and ultrasound clamp," *Energy. Convers. Manag.*, vol. 140, pp. 91-97, May 2017.
- [24] S. Dharma, H. H. Masjuki, H. C. Ong, A. H. Sebayang, A. S. Silitonga, F. Kusumo, and T. M. I. Mahlia, "Optimization of biodiesel production process for mixed biodiesel using response surface methodology," *Energy. Convers. Manag.*, vol. 115, pp. 178-190, May 2016.

Copyright © 2020 by the authors. This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited (CC BY 4.0).



Krit Somnuk was born in Thailand. He studied mechanical engineering at the Prince of Songkla University (PSU), Thailand and finished his Ph.D in 2013. He is currently a lecturer in Mechanical Engineering Department, Faculty of Engineering, PSU. His current research interests include biodiesel, and renewable energy.



Pichai Eawlex was born in Thailand. He studied mechanical engineering at the Prince of Songkla University (PSU), Thailand and finished his master's degree in 2016. He is currently a senior engineering in factories in South of Thailand.



Jarernporn Thawornprasert was born in Thailand. He studied mechanical engineering at the Prince of Songkla University (PSU), Thailand and finished his master's degree in 2017. He is currently a researcher of the biodiesel research unit in Mechanical Engineering Department, Faculty of Engineering, PSU.



Gumpon Prateepchaikul was born in Thailand. He studied M.Eng.Sc. (Mech. Eng.), in University of New South Wales, Australia. He is currently a senior lecturer in Mechanical Engineering Department, Faculty of Engineering, Prince of Songkla University (PSU). His current research interests include biodiesel, and renewable energy.