

Synthesis and use of a catalyst in the production of biodiesel from Pongamia Pinnata seed oil with dimethyl carbonate

Balaji M. Panchal & Hazem M. Kalaji

To cite this article: Balaji M. Panchal & Hazem M. Kalaji (2017): Synthesis and use of a catalyst in the production of biodiesel from Pongamia Pinnata seed oil with dimethyl carbonate, International Journal of Green Energy, DOI: [10.1080/15435075.2017.1313739](https://doi.org/10.1080/15435075.2017.1313739)

To link to this article: <http://dx.doi.org/10.1080/15435075.2017.1313739>



Accepted author version posted online: 12 Apr 2017.
Published online: 12 Apr 2017.



Submit your article to this journal [↗](#)



Article views: 13



View related articles [↗](#)



View Crossmark data [↗](#)



Synthesis and use of a catalyst in the production of biodiesel from *Pongamia Pinnata* seed oil with dimethyl carbonate

Balaji M. Panchal^a and Hazem M. Kalaji^{b,c}

^aNurture Earth Research and Development Pvt. Ltd., MIT, Aurangabad, Maharashtra, India; ^bDepartment of Plant Physiology, Warsaw University of Life Sciences-SGGW, Nowoursynowska, Warsaw, Poland; ^cSI TECHNOLOGY Sp. Z. O. O., Gorczewska, Warsaw, Poland

ABSTRACT

The preparation of sodium methoxide-treated algae catalysts and their activity in the transesterification of *Pongamia pinnata* seed oil by dimethyl carbonate were investigated. We also investigated the effect of the sodium methoxide-treated algae catalyst on the biodiesel yield. The development of sodium methoxide-treated algae catalysts can overcome most problems associated with dissolution in dimethyl carbonate. The products were analyzed using gas chromatography-mass spectroscopy to identify the fatty acid methyl esters in the biodiesel produced. The molar ratio of *Pongamia pinnata* seed oil to dimethyl carbonate in transesterification in the presence of the sodium methoxide-treated algae catalyst was observed to play a substantial role in this study, wherein the *Pongamia pinnata* seed oil conversion increased with increasing catalyst concentration. The highest percent conversion rate was 97%. With intense research focus and development, an ideal catalyst can indeed be developed for optimal biodiesel production that is both economically feasible and environmentally benign.

KEYWORDS

Algae; biodiesel; catalyst separation; *Pongamia pinnata* seed oil; Sodium methoxide-treated algae catalyst; transesterification

Introduction

The depletion of world petroleum reserves together with ever-increasing environmental concerns have stimulated the search for alternative renewable fuels that can fulfill the increasing demand for energy (Cai et al. 2015; Narasimharao, Lee, and Wilson 2007; Yang et al. 2014). In recent decades, research on and knowledge of the external benefits of renewable raw materials have intensified efforts toward sustainable energy sources. Biodiesel plays a major role in this field because of the worldwide research and deployment activities surrounding this sustainable energy source (Narasimharao, Lee, and Wilson 2007). Biodiesel is renewable, sustainable, and biodegradable and emits small amounts of greenhouse gases (Agarwal, Gupta, and Rajdeep 2015; Lee et al. 2010; Sharma and Singh 2009). The tax incentive for biodiesel production is considerable because of its high biodegradation (Meher, Dharmagadda, and Naik 2006; Syamsuddin and Hameed 2015), low CO₂ emissions (Ortiz-Martinez et al. 2016), sulfur-free emission, and high flash point (Lai 2014; Macario et al. 2010) compared with those of conventional diesel. The cost of biodiesel remains high because feedstock accounts for 80% of the production cost (Cai et al. 2015). In addition, an oxygen content of 11–15% in the molecular structure speeds up the combustion process in compression ignition engines and decreases the amount of pollutants such as soot, fine particles, and carbon monoxide (CO) (Kim et al. 2007; Lee, Lee, and Hong 2011).

Various types of edible oils are used as feedstock for biodiesel production. The use of vegetable oil as a raw

material for biodiesel synthesis must also consider the issue of food versus fuel competition. Hence, the utilization of non-edible vegetable oil has received considerable recent attention. However, nonedible vegetable oil usually has a high acid content, which can reduce the quality and biodiesel yield (Syamsuddin, Murat, and Hameed 2016). *Pongamia pinnata* is a medium-sized fast-growing leguminous tree native to humid subtropical climates (Ortiz-Martinez et al. 2016) that can grow under a wide range of agro-climatic conditions. In India, the *Pongamia pinnata* tree is available in more than 15 states with an oil potential of 135 Mtpa (Bala et al. 2011).

Currently, the base-catalyzed transesterification procedure is the most common and commercially available process for biodiesel production. The nature of the catalyst used in the transesterification reaction is critical for conversion of triglycerides into biodiesel. As a result, different catalysts have been explored in this role. Conventionally, homogeneous alkaline catalysts such as NaOH, KOH, CH₃ONa, and CH₃OK are often used in biodiesel production (Darnoko and Cheryan 2000; Sharma, Singh, and Upadhyay 2008).

Dimethyl carbonate (DMC) is a versatile compound due to its eco-friendliness, low chemical reactivity and favorable physical properties (Memoli, Selva, and Tundo 2001). DMC is a neutral, non-toxic, and non-corrosive compound that exhibits good solvent properties (Kurle, Islam, and Benson 2013; Rathore et al. 2015). Currently, methanol, oxygen and carbon monoxide are used to produce DMC via a safer reaction path than that involving phosgene (Aouissi, Al-Othman, and Al-Amro 2010). The reaction is attractive because DMC

Table 1. Properties of biodiesel using sodium-methoxide treated algal catalyst with *Pongamia pinnata* seed oil compared with ASTM D6751-02 specifications.

Properties	Units	ASTM method	Limits	Biodiesel
Kinematic viscosity at 40 °C	mm ² /sec	D445	1.9–6.0	3.69
Density at 25 °C	g/cm ³	D4052	Report	0.82
Flash point (closed cup)	°C	D93	130	128
Cloud point	°C	D2500	3 to 12	7
Pour point	°C	D97	10 to 15	–2
Copper strip corrosion (3 hrs at 50 °C)	No	D130	3 max	No. 1a
Acid value	mgKOH/g	D664	0.8	0.4
Water and sediment % vol. max	% vol.	D2709	0.05	0.007
Carbon residue	wt%	D45309	0	0
Ash content	wt%	D874	Max 0.02	0.002

is thought to be an ideal green reagent due to its low toxicity and environmental inertness (Delledonne, Rivetti, and Romano 2001; Tundo and Selva 2002), and DMC can also be used as a transesterification reagent for oils (Kai et al. 2014; Renga and Coms 1993). Studies have been conducted on the transesterification of different types of vegetable oils with DMC (Kai et al. 2014; Kurle, Islam, and Benson 2013; Rathore et al. 2015)

In previous studies using alkaline catalysts, high yields of biodiesel were not achieved under mild conditions such as those used in the production of DMC biodiesel. In this study, a new catalyst preparation method is proposed for a dried algae biomass treated with 3 N sodium methoxide. Sodium methoxide treated algae catalyst is noncorrosive and increases the rate of reaction. The effects of the reaction on the conversion of *Pongamia pinnata* seed oil were studied to obtain the optimal results. These results occurred with the use of 3.0 wt.% of 3 N sodium-methoxide-treated algae, a reaction time of approximately 90 min at reflux temperature, and a molar ratio of *Pongamia pinnata* seed oil to DMC of 1:4.

Materials and methods

Collection of materials

Pongamia pinnata seed oil was purchased from the manufacturer (Indian Biodiesel Corporation, Baramati, Pune (MH),

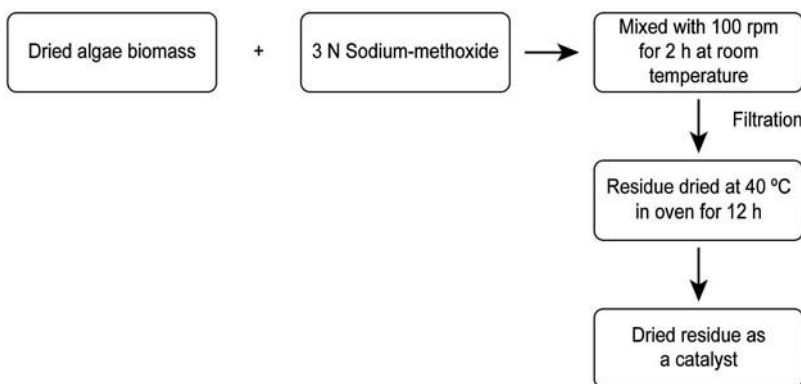
India). The reagents were 99.99% pure and thus were used without any need for further purification. All other chemicals and reagents were of analytical reagent grade and were purchased from Spectrochem Pvt. Ltd. Mumbai, India. All pure biodiesel standards were obtained from Sigma Chemical Company (St. Louis, MO, USA).

Preparation of catalyst

The methanol was distilled to remove moisture, and the moisture-free methanol was used to prepare a sodium hydroxide-methanol (NaOCH₃) solution. The alcohol-catalyst solution was freshly prepared to ensure its catalytic activity and prevent moisture absorption. The catalyst was prepared in a 1000 mL, 3-neck, round-bottom flask equipped with a reflux condenser. The chemical reagent (sodium hydroxide) was not soluble in DMC. In this case, the catalyst was prepared as follows. The algae (*Lemnoideae*) were treated with 3 N sodium methoxide in a 1:4 w/w ratio (100 g algae biomass:400 g 3 N sodium methoxide) at room temperature with stirring. The fine solution of 3 N sodium methoxide was suspended in a single-phase solution of algae at room temperature for 2 h with an agitation speed of 100 rpm. After 2 h, this suspension was filtered under vacuum to remove the methanol. After the methanol was removed, the residue (treated algae) was dried in an oven at 40°C for 12 h. Figure 1 shows the synthesis process for the 3 N sodium methoxide-treated algae catalyst. The dried treated algae were used as a catalyst for the transesterification reaction. The acid value was determined by titration with KOH, and the water content was measured using the Karl Fischer titration method.

Catalyst testing of transesterification

Transesterification was performed in a 1000 mL, 3-neck, round-bottom flask equipped with a reflux condenser, a water bath, a thermometer and a mechanical stirrer. The reaction was performed at reflux temperature for 90 min. *Pongamia pinnata* seed oil and DMC were used as the reactants. The average calculated molecular weight of the *Pongamia pinnata* seed oil was 870 g/mol. The molar ratio of *Pongamia pinnata* seed oil to DMC varied from 1:2 to 1:5. The catalyst loading varied from 1.0 to 3.5% w/w based on the

**Figure 1.** Diagram of the synthesis of a catalyst from algae biomass using sodium methoxide.

DMC weight, and the reaction time was 90 min. The reaction temperature was held constant at 85 °C (reflux) for the batch operation under standard conditions, and the agitation speed was varied from 25 to 175 rpm. Three layers were produced, namely, the excessive solvent phase, the biodiesel phase, and the glycerol carbonate phase, corresponding to the upper layer, middle layer and catalyst (treated algal biomass) lower layer, respectively. The collected sample was allowed to settle via gravity for 3 h in a separation funnel, which resulted in a clear, golden, liquid biodiesel on the top and a light brown glycerol carbonate (GC) on the bottom. The GC was drained from the separation funnel. The biodiesel phase was collected, and the excess DMC was evaporated from the biodiesel in a rotary vacuum evaporator at 30 °C and collected in a flask. The crude biodiesel was purified using 0.5% Magnesol® powder. The high-purity biodiesel was analyzed using gas chromatography-mass spectrometry (GC-MS), and the methyl ester yield (%) was determined. The biodiesel properties were determined using standard ASTM international methods. All experiments in this study were conducted in three replicates, and the results were analyzed via ANOVA.

Analysis of *Pongamia pinnata* seed oil biodiesel by GC-MS

The *Pongamia pinnata* seed oil biodiesel components were analyzed using a GC-MS (model GC6890 N gas chromatograph, model MS5973 MSD mass selective detector). Separation was performed in a capillary column (DB-5MS, 30 m × 0.32 mm, 0.25 µm film thickness). The carrier gas was helium with a flow rate of 1.5 mL/min. The column temperature was programmed to increase from 120 to 300°C at a rate of 10°C/min. A sample volume of 0.1 µL in chloroform was injected using the split mode with a split ratio of 1:10. The mass spectrometer was set to scan the m/z range from 50 to 550 using the electron impact (EI) ionization mode.

Properties of *Pongamia pinnata* seed oil biodiesel

The properties of the biodiesel produced from *Pongamia pinnata* seed oil and DMC using 3 N sodium methoxide-treated algae catalysts were determined according to a 2003 ASTM specification. The specific gravity, kinematic viscosity, flash point, cloud point, pour point, copper strip corrosion

and acid value were all determined in accordance with the ASTM D5002, ASTM D445, ASTM D93, ASTM D2500, ASTM D97, ASTM D130 and ASTM D664 standards, respectively (Rengasamy et al. 2014).

Results and discussion

Pongamia pinnata seed oil composition

Crude *Pongamia pinnata* seed oil contains at least 23% saturated fatty acids (stearic and palmitic acids) and 73% unsaturated fatty acids (oleic and linoleic acids) (Khayoon and Hameed 2012) as well as palmitic acid (C16) (11.65%), stearic acid (C18) (7.50%), oleic acid (C18:1) (51.59%), linoleic acid (18:2) (16.64%), eicosanoic acid (C20) (1.35%), docosanoic acid (C22) (4.45%), and tetracosanoic acid (C24) (1.09%) (Naik et al. 2008; Vuppaladadiyam, Sangeetha, and Sowmya 2013).

Effect of the catalyst normality on the biodiesel yield at reflux temperature

Catalyst normality is important in transesterification because the catalyst normality converts oil into biodiesel during the transesterification reaction. The catalyst normality is one of the most important factors that govern the quantity of biodiesel produced. The biodiesel production reactions were performed using a molar ratio of *Pongamia pinnata* seed oil to DMC of 1:4 at 85°C (reflux) for 90 min with an agitation speed of 150 rpm. Several catalyst normalities of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 N and a constant treated catalyst concentration of 3.0 wt.% based on the DMC weight were investigated. The results are presented in Figure 2, which shows the biodiesel yield percentage of 0.5–3.5 N catalysts. According to these results, the 3.0 N catalyst produced a better yield than the 2.0 and 2.5 N catalysts, whereas the 3.5 N catalyst produced an identical yield of 97%. Increasing the concentration of catalyst has a positive effect on the yield of biodiesel (Makareviciene et al. 2014).

Effect of the sodium methoxide-treated algae catalyst concentration on the biodiesel yield at reflux temperature

A catalyst is a substance that participates in a chemical reaction and increases the reaction rate without undergoing a net

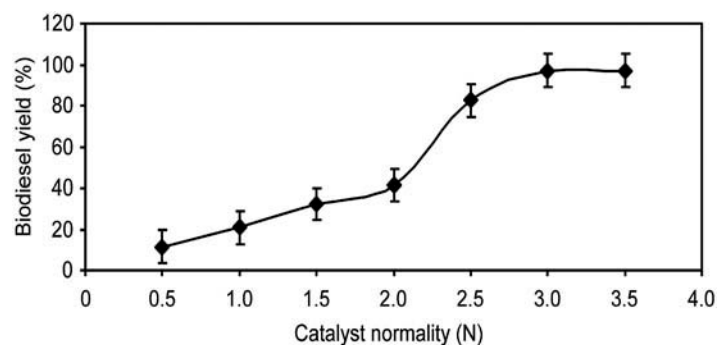


Figure 2. Effect of catalyst normality on biodiesel production. Reaction conditions: A 1:4 molar ratio of *Pongamia pinnata* seed oil to DMC and an agitation speed of 150 rpm at reflux for 90 min. The catalyst normality was varied. Data are represented as the mean ± standard deviation of triplicate experiments.

chemical change itself (Syamsuddin, Murat, and Hameed 2016). Biodiesel was produced from *Pongamia pinnata* seed oil using the sodium methoxide-treated algae catalyst. Biodiesel production via transesterification with sodium methoxide-treated algae as the catalyst can be increased through the use of a higher catalyst concentration. The effect of different concentrations of treated 3 N algae catalyst (1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 wt.% based on the DMC weight of the biodiesel yield from *Pongamia pinnata* seed oil) was investigated. The operating conditions were fixed at the *Pongamia pinnata* seed oil to DMC molar ratio of 1:4, the reflux temperature, a reaction time of 90 min, and an agitation speed of 150 rpm. When the catalyst concentration was increased from 2.5 to 3.0 wt.%, the biodiesel yield significantly increased from 89 to 97%, as shown in Figure 3. However, varying the catalyst concentration (from 1.0 to 2.0 wt.% based on the DMC weight) did not result in a substantial difference in biodiesel yield. This result indicates that the process reached equilibrium in the presence of the 3.0 wt.% catalyst. The biodiesel yield decreased when an excess catalyst concentration (3.0 wt.% based on the DMC weight) was used. These results are consistent with those reported by D'Oca et al. (2011). Thus, a concentration of 3.0 wt.% of sodium methoxide-treated algae was considered the optimal catalyst concentration.

Sodium methoxide-treated algal catalysts are noncorrosive, exhibit high selectivity and can be easily separated from other products. A good mixing efficiency is required to overcome the mass transfer limitations imposed by two-phase zones (solid to liquid) in sodium methoxide-treated algal catalysts. The reaction must be performed at high temperatures and at high alcohol-to-oil ratios. Overcoming the diffusion limitation shifts the equilibrium between products and yields improves conversion (97%) with minimal side reactions and a short reaction time.

Effect of DMC volume on the biodiesel yield at reflux temperature

DMC is important in transesterification because it is the reactant that converts oil into biodiesel. The amount of DMC is one of the most important factors that affects the quality and quantity of the biodiesel produced. As reported in

a previous study, DMC converts lipids into biodiesel. Panchal et al. (2013) determined the appropriate weight for *Pongamia pinnata* seed oil transesterification, and a series of molar ratios of *Pongamia pinnata* seed oil to DMC (w/w) (1:1, 1:2, 1:3, 1:4 and 1:5) was used to produce biodiesel. The conversion increased when the ratio of DMC to oil increased (Kai et al. 2014). In these experiments, 3.0 wt.% of treated algae was added (based on DMC weight) at 85 °C (reflux) for 90 min and agitated at a speed of 150 rpm. The results are shown in Figure 4. The biodiesel yield was enhanced from 40% to 97% when the molar ratio of *Pongamia pinnata* seed oil to DMC was increased from 1:1 to 1:4. The highest biodiesel yield of 97% was obtained with a 1:4 molar ratio of *Pongamia pinnata* seed oil to DMC. A further increase in the DMC amount did not substantially improve the biodiesel yield. Based on this result, a 1:9 molar ratio of oil to DMC produced a 95.8% biodiesel yield (Dawodu et al. 2014). Generally, increasing the amount of alcohol increased the reaction rate, which resulted in a higher yield within a shorter time. The excess DMC possibly increased the polarity of reaction mixtures, thus promoting the reverse reaction and decreasing the FAME yield (Ayeter, Sunnu, and Parbey 2015; Prommuak et al. 2012). Therefore, a molar ratio of *Pongamia pinnata* seed oil to DMC of 1:4 is considered suitable for the production of biodiesel from *Pongamia pinnata* seed oil. This molar ratio is remarkably effective and efficient.

Effect of the reaction time on the biodiesel yield at reflux temperature

The reaction time is another factor that can affect the biodiesel yield from *Pongamia pinnata* seed oil. Panchal, Deshmukh, and Sharma (2016) reported a conversion increase in fatty acid esters as a result of an increase in reaction time. In the biodiesel production experiment, reaction times of 15, 30, 45, 60, 75, 90 and 105 min were investigated. The reactions were performed at reflux temperature using a molar ratio of *Pongamia pinnata* seed oil to DMC of 1:4, 3.0 wt.% of sodium methoxide-treated algae (based on DMC), and an agitation speed of 150 rpm. The reaction was slow at first because of the mixing and dispersion of DMC and *Pongamia pinnata* seed oil. The reaction rapidly proceeded, as shown in Figure 5, which presents the biodiesel yield percentage for 15–105 min

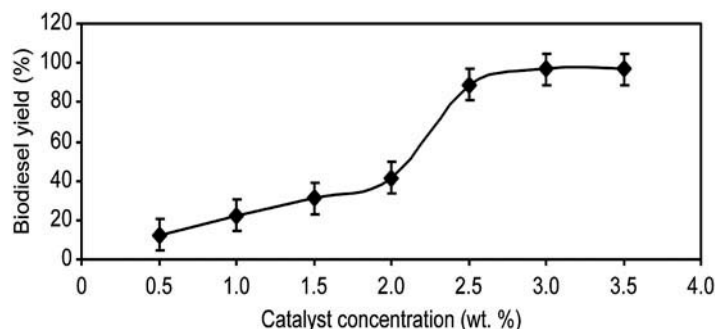


Figure 3. Effect of 3 N sodium methoxide-treated algae catalyst concentration on biodiesel production. Reaction conditions: A 1:4 molar ratio of *Pongamia pinnata* seed oil to DMC and an agitation speed of 150 rpm at reflux for 90 min. The 3 N sodium methoxide-treated algae catalyst concentration was varied. Data are represented as the mean \pm standard deviation of triplicate experiments.

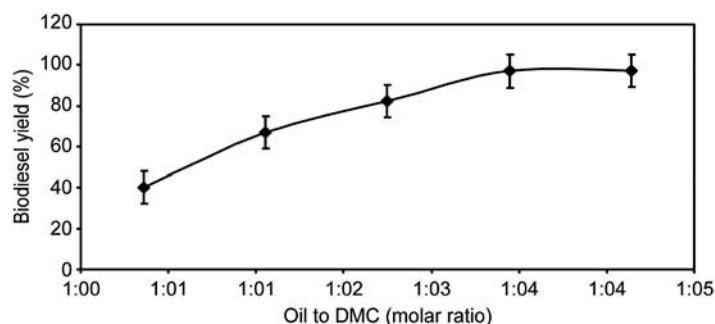


Figure 4. Effect of molar ratio of *Pongamia pinnata* seed oil to DMC on biodiesel production. Reaction conditions: A 3 N sodium methoxide-treated algae catalyst concentration of 3.0 wt.% and an agitation speed of 150 rpm at reflux for 90 min. The molar ratio of *Pongamia pinnata* seed oil to DMC was varied. Data are represented as the mean \pm standard deviation of triplicate experiments.

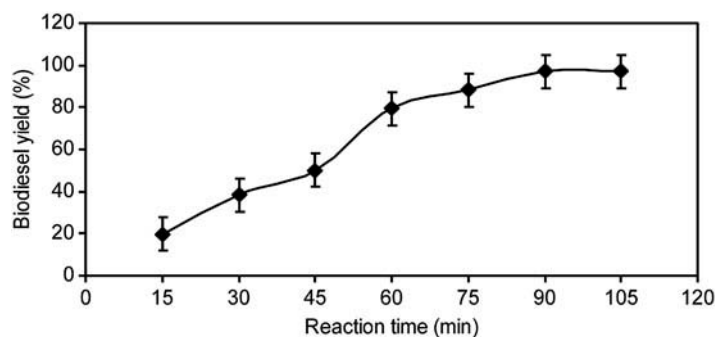


Figure 5. Effect of reaction time on biodiesel production. Reaction conditions: A 1:4 molar ratio of *Pongamia pinnata* seed oil to DMC, a 3 N sodium methoxide-treated algae catalyst concentration of 3.0 wt.%, and an agitation speed of 150 rpm. The reaction time was varied. Data are represented as the mean \pm standard deviation of triplicate experiments.

of reaction time. The results show that 90 min of reaction time produced a better yield than 60 and 75 min of reaction time, whereas 105 min of reaction time also produced a yield of 97%. However, the maximum biodiesel conversion was achieved within 90 min. An additional increase in reaction time did not substantially increase the yield (97.10%). Increases in reaction time did not affect the methyl ester yield because the conversion of oil into methyl ester yield was completed (Kumar and Sharma 2016). Patil et al. (2011) that reported an extended reaction time might result in overheating of the reaction mixture, greater solvent losses, and energy losses. The biodiesel yield remained relatively constant with further increases in reaction time (Leung and Guo 2006).

Effect of agitation speed on the biodiesel yield at reflux temperature

Agitation intensity appears to be particularly important for the methyl ester process. The reaction can only occur in the interfacial region between the liquids, and alcohols are not completely miscible. As a result, vigorous mixing is required to increase the contact area between the two immiscible phases (Gashaw and Teshita 2014; Singh and Fernando 2006). Therefore, in this study, the agitation speed was varied to improve the biodiesel yield. Agitation speeds of 25, 50, 75, 100, 125, 150, and 175 rpm were investigated. The biodiesel yield increased with increased agitation speed up to a point and subsequently decreased. The agitation speed of 150 rpm

resulted in the highest biodiesel yield of 97%. An agitation speed of 175 rpm also produced a biodiesel yield of 97% (Figure 6), and thus, no further increase in percentage conversion was observed at 175 rpm. Thus, the optimal agitation speed for methyl ester formation was 150 rpm. This result corresponds with the effect of agitation speed on the reaction mixture, which is important to ensure proper mixing of the reactants and completion of the conversion process (Mohan and Kannan 2016; Ogunsuyi 2012).

Reuse of the sodium methoxide-treated algae catalyst

Because the sodium methoxide-treated algae catalyst exists in a solid state, it can be separated from the liquid mixture by filtration after the reaction is completed. The activity of the reused catalyst was measured to confirm that the catalyst could be used repeatedly. The reactions with the used catalyst were performed using 3.0 wt.% catalyst (based on DMC weight), a molar ratio of *Pongamia pinnata* seed oil to DMC of 1:4, a reaction temperature of 85 °C, a reaction time of 90 min, and an agitation speed of 150 rpm. The biodiesel conversion yield of the reactions conducted using the reused catalyst was 71.40%, which implies that the activity of the reused catalyst sharply decreased in the first reaction regardless of the difference in reaction temperature. One of the major advantages of the sodium methoxide-treated algal catalyst is its reusability or regeneration because the catalyst is not difficult to separate from other products.

GC-MS analysis of the biodiesel

GC-MS was used to determine the methyl ester groups in the biodiesel produced using *Pongamia pinnata* seed oil, DMC and 3 N sodium methoxide-treated algae catalysts. Figure 7 shows the GC-MS analysis results for biodiesel produced under optimal conditions using the 3 N sodium methoxide-treated algae catalyst. Eleven main characteristic peaks of methyl esters appeared at various retention times, and the GC-MS fragmentation pattern data are shown. Eleven methyl ester derivatives were detected in the biodiesel from *Pongamia pinnata* seed oil. The most abundant components were oleic acid methyl esters (41.13%), eicosenoic acid (24.51%), arachidic acid (7.81%), linoleic acid (6.38%), palmitic acid (4.98%), steric acid (3.02%), palmitoleic acid (2.79%), behenic acid (1.84%), alpha and gamma linoleic acid (0.94%), docosanoic acid (0.89%) and tetracosanoic acid (0.74%). The total content of methyl esters was 97%, which might explain the high quality of the biodiesel produced from *Pongamia pinnata* seed oil. Hence, the 3 N sodium methoxide-treated algae catalyst is suitable for biodiesel production.

Properties of biodiesel produced from *Pongamia pinnata* seed oil

The properties and specifications of the biodiesel as determined according to biodiesel testing standard ASTM

D6751-02 are summarized in Table 1, which shows that the 3 N sodium methoxide-treated algae catalyst in this experiment produced a biodiesel. The produced biodiesel had a kinematic viscosity of 3.69 mm²/s, which is within the range of the European Standard for biodiesels. Kinematic viscosity is a key fuel property because it promotes atomization of fuel upon injection into the ignition chamber of a diesel engine and governs the ultimate formation of engine deposits (Dawodu et al. 2014; Knothe and Steidley 2005). The flash point, which is an important characteristic with respect to the handling, storage and safety of fuels, was determined to be 128 °C for the biodiesel produced from *Pongamia pinnata* seed oil. The acid value is expressed as the mg KOH required to neutralize the fatty acid methyl esters. The maximum acid value for the European Standard ASTM D 664 is 0.4 mg KOH/g (Agbajelola et al. 2015; Ramos et al. 2009). The water content in biodiesel decreases the combustion heat and can cause corrosion in the fuel pumps and fuel tubes (Atabani et al. 2013). The pour point of the biodiesel is -2. The pour point is associated with engine performance under cold conditions (Gaurav and Sharma 2016; Nakpong and Wootthikanokkhan 2010). The water and sediment contents in the biodiesel from *Pongamia pinnata* seed oil prepared using 3 N sodium methoxide-treated algae catalyst were 0.005%. The ash content reflects the contents of

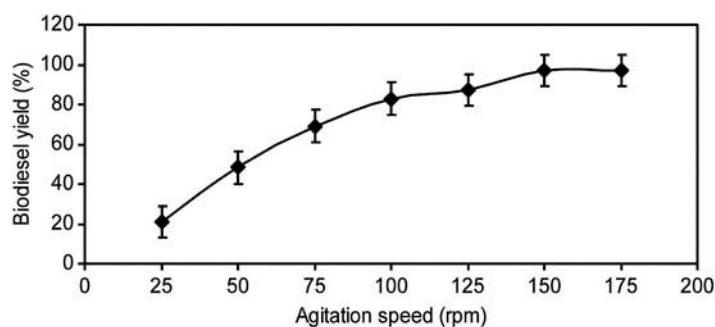


Figure 6. Effect of agitation speed on biodiesel production. Reaction conditions: A 1:4 molar ratio of *Pongamia pinnata* seed oil to DMC and a 3 N sodium methoxide-treated algae catalyst concentration of 3.0 wt.% at reflux with an agitation speed of 150 rpm for 90 min. The agitation speed was varied. Data are represented as the mean \pm standard deviation of triplicate experiments.

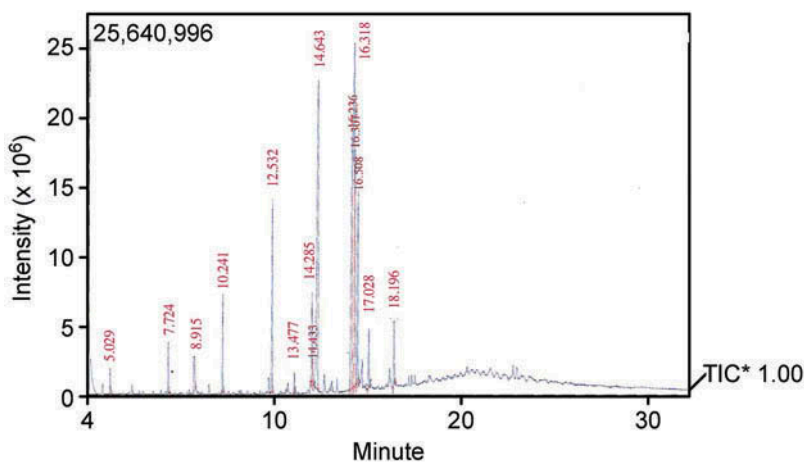


Figure 7. Chromatogram of biodiesel produced from *Pongamia pinnata* seed oil using a 3 N sodium methoxide-treated algae catalyst.

contaminants such as abrasive solids, catalyst residues, and soluble metal soaps in the fuel sample. In this study, the biodiesel had an ash content of 0.003%, which is within the limits of the ASTM standard.

Conclusion

The current study clearly shows that 3 N sodium methoxide-treated algae is a non-toxic and promising eco-friendly catalyst. The 3 N sodium methoxide-treated algae act as a strong basic catalyst for the transesterification of *Pongamia pinnata* seed oil with DMC. The 3 N sodium methoxide-treated algae catalysts are useful for commercial-scale biodiesel production because they are reusable and because the reaction is completed in less time. In the laboratory experiments, produced a biodiesel with properties that satisfy the ASTM standards for biodiesel and with a higher (%) yield. The new biodiesel process has the following advantages: (1) the biodiesel yield is high (97%); (2) good mixing efficiency can overcome the mass transfer limitations imposed by two-phase zones (solid to liquid) in sodium methoxide-treated algal catalysts; (3) sodium methoxide-treated algal catalysts are non-corrosive; and (4) downstream separation of the end products is more easily performed than with conventionally produced biodiesel. The most abundant components were oleic acid methyl esters (41.13%). Therefore, the 3 N sodium methoxide-treated algae catalyst was deemed an effective catalyst for the transesterification of *Pongamia pinnata* seed oil. The high yield and high purity of the biodiesel produced using this method together with its user friendliness and environmental compatibility suggest that it is commercially viable for biodiesel production.

Supporting information

Table 1. Properties of biodiesel using methoxide-treated algae catalyst with *Pongamia pinnata* seed oil compared with ASTM D6751-02 specifications.

Acknowledgments

The authors thank Prof. M.S. Kachole, Department of Biochemistry, and Dr. B. A. M. U. Aurangabad-Maharashtra, India, for valuable support.

References

- Agarwal, A., P. Gupta, and Rajdeep, A. 2015. Biodiesel production for C. I. engine from various non- edible oils: A review. *International Journal of Emerging Engineering Research and Technology* 3 (1):8–16.
- Agbajelola, D. O., M. Umar, I. A. Mohammed, B. Suleiman, and P. U. Asika. 2015. Optimization and characterization of biodiesel synthesis from chicken fat. *Journal of Multidisciplinary Engineering Science and Technology* 2 (7):1931–35.
- Aouissi, A., Z. A. Al-Othman, and A. Al-Amro. 2010. Gas-phase synthesis of dimethyl Carbonate from methanol and carbon dioxide over Co_{1.5}PW₁₂O₄₀ keggin-type heteropolyanion. *International Journal of Molecular Sciences* 11:1343–51. doi:10.3390/ijms11041343.
- Atabani, A. E., A. S. Silitonga, H. C. Ong, T. M. I. Mahlia, H. H. Masjuki, I. A. Badruddin, and H. Fayaz. 2013. Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. *Renewable and Sustainable Energy Review* 218:211–45.
- Ayeter, G. K., A. Sunnu, and J. Parbey. 2015. Effect of biodiesel production parameters on viscosity and yield of methyl esters: *Jatropha curcas*, *Elaeis guineensis* and *Cocos nucifera*. *Alexandria Engineering Journal* 54 (4):1285–90. doi:10.1016/j.aej.2015.09.011.
- Bala, M., T. N. Nag, S. Kumar, M. Vyas, A. Kumar, and N. S. Bhogal. 2011. Proximate composition and fatty acid profile of *Pongamia pinnata*, a potential biodiesel crop. *Journal of the American Oil Chemists Society* 88:559–62. doi:10.1007/s11746-010-1699-2.
- Cai, Z., Y. Wang, Y. Teng, K. Chong, J. Wang, J. Zhang, and D. Yang. 2015. A two-step biodiesel production process from waste cooking oil via recycling crude glycerol esterification catalyzed by alkali catalyst. *Fuel Processing Technology* 137:186–93. doi:10.1016/j.fuproc.2015.04.017.
- D'Oca, M. G. M., C. V. Viegas, J. S. Lemos, E. K. Miyasaki, J. A. Moron-Villarreyes, E. G. Primel, and P. C. Abreu. 2011. Production of FAMES from several microalgal lipidic extracts and direct transesterification of the *Chlorella pyrenoidosa*. *Biomass and Bioenergy* 35:1533–38. doi:10.1016/j.biombioe.2010.12.047.
- Darnoko, D., and M. Cheryan. 2000. Kinetics of palm oil transesterification in a batch reactor. *Journal of American Oil Chemical Society* 77:1263–67. doi:10.1007/s11746-000-0198-y.
- Dawodu, F. A., O. O. Ayodele, J. Xin, and S. Zhang. 2014. Dimethyl carbonate mediated production of biodiesel at different reaction temperatures. *Renewable Energy* 68:581–87. doi:10.1016/j.renene.2014.02.036.
- Delledonne, D., F. Rivetti, and U. Romano. 2001. Developments in the production and applications of dimethylcarbonate. *Applied Catalysis A* 221:241–51. doi:10.1016/S0926-860X(01)00796-7.
- Gashaw, A., and A. Teshita. 2014. Production of biodiesel from waste cooking oil and factors affecting its formation: A review. *International Journal of Renewable and Sustainable Energy* 3 (5):92–98.
- Gaurav, D., and M. P. Sharma. 2016. Investigation of cold flow properties of waste cooking biodiesel. *Journal of Clean Energy Technologies* 4 (3):205–08.
- Kai, T., G. L. Mak, S. Wada, T. Nakazato, H. Takanashi, and Y. Uemura. 2014. Production of biodiesel fuel from canola oil with dimethyl carbonate using an active sodium methoxide catalyst prepared by crystallization. *Bioresource Technology* 163:360–63. doi:10.1016/j.biortech.2014.04.030.
- Khayoon, M. S., and B. H. Hameed. 2012. Synthesis of hybrid SBA-15 functionalized with molybdophosphoric acid as efficient catalyst for glycerol esterification to fuel additives. *Applied Catalysis A General* 433:152–61.
- Kim, S., K. Kim, S. Shin, and E. Yim. 2007. Effect of catalyst in biodiesel production: A review. *Journal of the Korean Industrial and Engineering Chemistry* 18:401–06.
- Knothe, G., and K. R. Steidley. 2005. Kinematic viscosity of biodiesel fuel components and related compounds. Influence of compound structure and comparison to petrodiesel fuel components. *Fuel* 84:1059–65. doi:10.1016/j.fuel.2005.01.016.
- Kumar, M., and M. P. Sharma. 2016. Kinetics of *Chlorella protothecoides* microalgal oil using base catalyst. *Egyptian Journal of Petroleum* 25:375–82. doi:10.1016/j.ejpe.2015.08.005.
- Kurle, Y. M., M. R. Islam, and T. J. Benson. 2013. Process development and simulation of glycerol-free biofuel from canola oil and dimethyl carbonate. *Fuel Processing Technology* 114:49–57. doi:10.1016/j.fuproc.2013.03.030.
- Lai, E. P. C. 2014. Biodiesel: Environmental friendly alternative to petrodiesel. *Journal of Petroleum Environmental Biotechnology* 5 (1):1000–122.
- Lee, S. B., K. H. Han, J. D. Lee, and I. K. Hong. 2010. Optimum process and energy density analysis of canola oil biodiesel synthesis. *Journal of Industrial Engineering Chemistry* 16:1006–10. doi:10.1016/j.jiec.2010.09.015.
- Lee, S. B., J. D. Lee, and I. K. Hong. 2011. Ultrasonic energy effect on vegetable oil based biodiesel synthesis process. *Journal of Industrial Engineering Chemistry* 17:138–43.
- Leung, D. Y. C., and Y. Guo. 2006. Transesterification of neat and used frying oil: Optimization for biodiesel production. *Fuel Processing Technology* 87:883–90. doi:10.1016/j.fuproc.2006.06.003.

- Macario, A., G. Giordano, B. Onida, D. Cocina, A. Tagarelli, and A. M. Giuffrè. 2010. Biodiesel production process by homogeneous/heterogeneous catalytic system using an acid–base catalyst. *Applied Catalysis A* 378:160–68. doi:10.1016/j.apcata.2010.02.016.
- Meher, L. C., V. S. S. Dharmagadda, and S. N. Naik. 2006. Methanolysis of *Pongamia pinnata* (Karanja) oil for production of biodiesel. *Bioresource Technology* 97:1392–97. doi:10.1016/j.biortech.2005.07.003.
- Memoli, S., M. Selva, and P. Tundo. 2001. Dimethyl carbonate for eco-friendly methylation reactions. *Chemosphere* 43:115–21. doi:10.1016/S0045-6535(00)00331-3.
- Mohan, S. K., and T. K. Kannan. 2016. Optimization and production of biodiesel from cottonseed oil and neem oil. *International Journal of Modern Science and Technology* 01 (01):23–28.
- Naik, M., L. C. Meher, S. N. Naik, and L. M. Das. 2008. Production of biodiesel from high free fatty acid Karanja (*Pongamia pinnata*) oil. *Biomass and Bioenergy* 32 (4):354–57. doi:10.1016/j.biombioe.2007.10.006.
- Nakpong, P., and S. Wootthikanokkhan. 2010. Optimization of biodiesel production from *Jatropha curcas* L. Oil via alkali-catalyzed methanolysis. *Journal of Sustainable Energy Environment* 1:105–09.
- Narasimharao, K., A. Lee, and K. Wilson. 2007. Catalysts in production of biodiesel: A review. *Journal of Biobased Materials and Bioenergy* 1:19–30.
- Ogunsuyi, H. O. 2012. Acid and base catalyzed transesterification of mango (*Mangifera indica*) seed oil to biodiesel. *Journal of Applied Chemistry* 2:18–22.
- Ortiz-Martinez, V. M., M. J. Salar-Garcia, F. J. Palacios-Nereob, P. Olivares-Carrillo, J. Quesada-Medina, A. P. De Los Rios, and F. J. Hernandez-Fernandez. 2016. In-depth study of the transesterification reaction of *Pongamia pinnata* oil for biodiesel production using catalyst-free supercritical methanol process. *Journal of Supercritical Fluids* 113:23–30. doi:10.1016/j.supflu.2016.03.009.
- Panchal, B. M., S. A. Deshmukh, and M. R. Sharma. 2016. Biodiesel from *Thevetia peruviana* seed oil with dimethyl carbonate using as an active catalyst potassium-methoxide. *Sains Malaysiana* 45 (10):1461–68.
- Panchal, B. M., S. B. Dhoot, S. A. Deshmukh, M. R. Sharma, and M. S. Kachole. 2013. Production of DMC- BioD from *Pongamia pinnata* seed oil using dimethyl carbonate. *Fuel* 109:201–05. doi:10.1016/j.fuel.2012.12.052.
- Patil, P. D., V. G. Gude, A. Mannarswamy, S. Deng, P. Cooke, M.-M. I. Rhodes, P. Lammers, and N. N. Khandan. 2011. Optimization of direct conversion of wet algae to biodiesel under supercritical methanol conditions. *Bioresource Technology* 102:118–22. doi:10.1016/j.biortech.2010.06.031.
- Prommuak, C., P. Pavasant, A. T. Quitain, M. Goto, and A. Shotipruk. 2012. Microalgal lipid extraction and evaluation of single step biodiesel production. *Engineering Journal* 16:157–66. doi:10.4186/ej.2012.16.5.157.
- Ramos, M. J., C. M. Fernandez, A. Cases, L. Rodriguez, and A. Perez. 2009. Influence of fatty acid composition of raw materials on biodiesel properties. *Bioresource Technology* 100:261–68. doi:10.1016/j.biortech.2008.06.039.
- Rathore, V., S. Tyagi, B. Newalkar, and R. P. Badoni. 2015. Jatropha and Karanja oil derived DMC-biodiesel synthesis: A kinetics study. *Fuel* 140:597–98. doi:10.1016/j.fuel.2014.10.003.
- Renga, J. M., and F. D. Coms. 1993. Novel methods for the preparation of glycerol carbonate esters. Patent No. WO9309111 to Henkel Corp.
- Rengasamy, M., K. Anbalagan, S. Mohanraj, and V. Pugalenth. 2014. Biodiesel production from *Pongamia pinnata* oil using a synthesized iron nanocatalyst. *International Journal of Chem Tech Research* 6:4511–16.
- Sharma, Y. C., B. Singh, and S. N. Upadhyay. 2008. Advancements in development and characterization of biodiesel: A review. *Fuel* 12:2355–73.
- Sharma, Y. C., and B. R. Singh. 2009. Development of biodiesel: Current scenario. *Sustainable Energy Reviews* 13:16–46. doi:10.1016/j.rser.2008.08.009.
- Singh, A. K., and S. D. Fernando. 2006. Catalyzed fast transesterification of soybean oil using ultrasonication. American Society of Agricultural Engineers. Annual Meeting, Portland, OR, July.
- Syamsuddin, Y., and B. H. Hameed. 2015. Synthesis of glycerol free- fatty acid methyl esters from Jatropha oil over Ca- Lamixed-oxide catalyst. *Journal of the Taiwan Institute of Chemical Engineers*. doi:10.1016/j.jtice.2015.06.041.
- Syamsuddin, Y., M. N. Murat, and B. H. Hameed. 2016. Synthesis of fatty acid methyl ester from the transesterification of high- and low-acid-content crude palm oil (*Elaeis guineensis*) and Karanj oil (*Pongamia pinnata*) over a calcium–lanthanum–aluminum mixed-oxides catalyst. *Bioresource Technology* 214:248–52. doi:10.1016/j.biortech.2016.04.083.
- Tundo, P., and M. Selva. 2002. The chemistry of dimethyl carbonate. *Accounts of Chemical Research* 35:706–16. doi:10.1021/ar010076f.
- Vuppalladadiyam, A. K., C. J. Sangeetha, and V. Sowmya. 2013. Transesterification of *Pongamia pinnata* oil using base catalysts: A laboratory scale study. *Universal Journal of Environmental Research and Technology* 3 (1):113–18.
- Yang, S., L. Qing, G. Yang, Z. Longyu, and L. Ziduo. 2014. Biodiesel production from swine manure via housefly larvae (*Musca domestica* L.). *Renewable Energy* 66:222–27. doi:10.1016/j.renene.2013.11.076.