The current state applications of ethyl carbonate with ionic liquid in sustainable biodiesel production: A review

Balaji Panchal [a], Zheng Zhu [a,b], Shenjun Qin [a,b,*], Tao Chang [a,b,**], Qiaojing Zhao [a], Yuzhuang Sun [a,c,***], Cunliang Zhao [a,c,****], Jinxi Wang [a], Kai Bian [a], Santosh Rankhamb [d]

[a] Key Laboratory of Resource Exploration Research of Hebei University of Engineering, Handan, 056038, Hebei, China
[b] Key Laboratory of Utilization of CO₂ of Handan City, College of Material Science and Engineering, Hebei University of Engineering, Handan, Hebei, 056038, China
[c] College of Earth Science and Engineering, Hebei University of Engineering, Handan, 056038, Hebei, China
[d] Dept of Zoology, Late Ramesh Warpudkar ACS College Sonpeth, Parbhani, MS, India

ARTICLE INFO

ABSTRACT

Driven by the high energy demand and environmental concerns, biodiesel as a substitute for fossil fuels is recognized as promising renewable and clean energy. Biodiesel has gained interest around the world over the last few years because it could be used to reduce most regulated exhaust emissions. Herein, we discuss the application of catalytic transesterification by using ionic liquids (ILs) catalyst with alcohol and waste oil for the clean synthesis of biodiesel in order to reduce the emission of NOₓ and CO. However, the running cost of this process is still higher than that of the conventional chemical transesterification. Non-edible sources such as waste oil, non-edible vegetable oil, and waste animal oil are commonly used to produce biodiesel due to their low cost and no dependency on the food chain. This review provides an overview of the recent progresses in improving the biodiesel production process by using ILs and determining the activation energy and the properties of the finished product. In addition, the future direction in biodiesel production via ILs catalysis in the transesterification has been discussed.

© 2021 Elsevier Ltd. All rights reserved.

Contents

* Corresponding authors. Key Laboratory of Resource Exploration Research of Hebei University of Engineering, Handan, 056038, Hebei, China.
** Corresponding author. Key Laboratory of Resource Exploration Research of Hebei University of Engineering, Handan, 056038, Hebei, China.
*** Corresponding authors. Key Laboratory of Resource Exploration Research of Hebei University of Engineering, Handan, 056038, Hebei, China.
**** Corresponding author. Key Laboratory of Resource Exploration Research of Hebei University of Engineering, Handan, 056038, Hebei, China.
E-mail addresses: qinsj26@hebeu.edu.cn (S. Qin), changt03@sina.com (T. Chang), syz@hebeu.edu.cn (Y. Sun), zhaocunliang@hebeu.edu.cn (C. Zhao).

1. Introduction

Novel technologies are being developed to overcome the disadvantages associated with the biodiesel production processes. The demand for energy is gradually increasing in every sector (e.g., transportation, agriculture, and domestic), and this issue would consequently lead to fuel shortage owing to the gradual decline in fossil fuel reserves [1]. Biofuels are obtainable from renewable sources like plants, crops, and agricultural and forestry by-products, offering sustainability, energy security, and environmental compatibility [2]. Sustainability is an overarching concept connecting nations, economies, and national communities through developmental considerations in the environmental, economic, and societal realms. Indeed, many national agencies of People's Republic of China (Environmental Protection Agency, National Natural Science Foundation of China Agency, the Science and Technology Foundation of University Agency, etc.) have specific policies of sustainability.

Biodiesel is a mono-alkyl ester of long-chain fatty acids produced by the transesterification of vegetable oils, animal fats [3], and waste cooking oil [4]. Globally, numerous non-edible vegetable oil plants are naturally available such as Jatropha curcas, Maduca indica, and Pongamia pinnata, represent second-generation biodiesel feedstocks [5,6]. It has been reported that approximately 70–95% of biodiesel cost is attributed to raw feedstock cost [7]. Most of these crops are grown in Southeast Asia and have been successfully introduced in humid tropical regions of the world and parts of China [8]. Several researches have been recently published regarding biodiesel production from different sources shown in Table 1.

Methanol has been widely used in the transesterification of triglycerides. However, it is toxic and thus, non-toxic reagent is required for the transesterification process [9,10]. Diethyl carbonate (DEC) is a promising high oxygen-containing and biodegradable candidate, which can be produced by using ethanol and dimethyl carbonate (DMC) has been used as an acyl acceptor [11].

New generation polymer-based ILs for the transesterification of DEC has become the target of interest for many researchers studying biodiesel production because of their advantages and environmentally friendly nature [12]. DEC has been used in different capacities in the biodiesel production process (Fig. 1). Certain ILs that are regarded as "green" solvents have received worldwide attention in various fields, including catalysis [13]. according to previous researches, the functions of ILs vary considerably depending on their structural properties that may lead to improved reaction activity for reactants with large molecular size and surface areas, thermal, chemical stability, reusability, and water tolerance activity [14]. In recent years, the emerging concept of green chemistry using eco-friendly materials and ILs advanced catalysts for chemical transformations has gained immense attention; catalyst has significant negative effect towards environment [15]. Currently, homogeneous base catalysts, e.g. KOH and NaOH are generally being utilized in industry for biodiesel production [16]. Difficult catalyst separation and consequently high cost for product purification are the major drawbacks of homogeneous base catalysis systems [17]. homogeneous acid catalysts are difficult to recycle and need to high temperatures, and give rise to serious environmental problems [18].

They have been used in supercritical or non-supercritical transesterification [19]. enzymatic transesterification [20], and glycerol carbonate transesterification [21–23]. However, DMC-based catalytic transesterification is reported to be a time-consuming process and requires high amount of catalysts owing to the polarity difference between the reactant and catalyst [24]. In addition, engine tests indicated that 5 wt % DEC in diesel fuel could reduce almost 50% particulate emissions [25].

This review aims to provide a detailed account of the ways in which DEC and non-edible oil with ILs as catalyst has been used in the transesterification of biodiesel. review focuses on the non-edible oil sources, the kinetics of the reaction; and the properties of products and by-product application were evaluated, and future suggestions have been provided. The current knowledge on ILs catalysis, reusability, and deactivation as well as the influence of activation energy on the transesterification process are reviewed herein. We propose the major advantages associated with the usage of DEC with non-edible oil with ILs, such as environmental friendliness; however, as transesterification performed using DEC and ILs is not cost-effective, efforts are underway to reduce the cost.

2. Methodology

Articles for dialkyl carbonates such as DEC, DMC, ILs, feedstock, enzyme catalysts, and other catalysts were collected by searching through Scientific databases such as Science Direct, Springer, Baidu

Table 1
Summary of transesterification reaction involving various alcohol.

| Oil	Solvents	Catalyst and amount	Temperature (°C)	Solvent:Oil (mol/mol)	Time (h)	Yields (%)	Refs
Palm oil	DEC/DMC	15 wt % KOH	100	14:1	20	90.8	[11]
Pistacia chinensis	DEC	300 wt % PEI	120	5:1	6	93	[14]
Jatropha curcas	DMC	9 wt % KOH	80	10:1	8	94	[23]
Pongamia pinnata	DMC	9 wt % KOH	80	10:1	8	96	[23]
Waste cooking oil	Triethylammoniumhy drogensulfate [Et₃NHSO₄]	5.2 wt % KOH	170	15:1	3	96.9	[26]
Canola oil	DMC	2 wt % Crystallized CH₃ONa	65	3:1	1	96	
Jatropha curcas	DMC	7 wt % CaO–La₂O₃–Al₂O₃	150	15:1	3	90	[39]
Canola oil	DMC	1.5 wt % Triazabicyclodecene (TBD)	70	3:1	2	97.99	[56]
Jatropha curcas	DMC	260 wt % [IMHPS][C₁₈], PIL	80	5:1	6	90	[100]
Waste cooking	DMC	2.5 wt % [HO₃S (CH₂)₃ NEt₃]Cl–FeCl₃	120	5:1	4	95	[101]
Free fatty acids	MeOH	10 wt % [DDPA][Tos]ₗ	60	1.5:1	3	92.5	[47]
Vegetable oil	DMC	5.2 wt % Biochar- pseudo-catalytic	380	36:1	2	95.4	[52]
Rapeseed oil	DMC	25 wt % [PrSO₃HMIM][HSO₄]	110	5:1	5	95.77	[82]
Soybean oil	MeOH	6 wt % 1,1,3,3-trimethyl-2-octyl-guanidine hydroxide (IL₁)	55	15:1	4	97	[132]
Sunflower oil	MeOH	0.43 wt % NaOH	40	4.5:1	2.5	96.5	[133]
Jatropha curcas	MeOH	2 wt % Bi₂O₃–La₂O₃	150	15:1	4	93	[134]
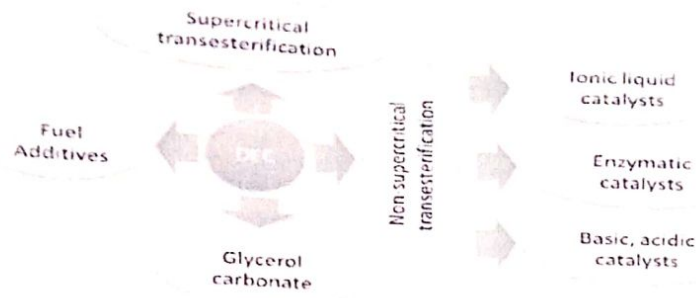
Fig. 1. Various application of DEC in the biodiesel production.

websites and Scopus. The main keywords used in the search for identifying the knowledge gap related to the selected topic included diethyl carbonate, biodiesel, dialkyl carbonate with ILs, dialkyl carbonate with enzyme catalysts, kinetic study, and properties of biodiesel published in peer reviewed journal in the year of study (2000–2021).

3. Effective and eco-environmental production of biodiesel by using ILs with DEC

The presence of a catalyst is an important during transesterification because it enhances the reaction rate and yield [26]. Methanol is especially used because of lower cost and its physical and chemical advantages. Dennis [27], reported that methanol can rapidly reacts with triglycerides, and most of the catalyst is easily dissolved in it. The good performance of DEC could be attributed to the lower hydrophobicity (log $P = 1.21$) and mutual solubility with triglycerides [15]. DEC has two times the oxygen content compared with other solvents and is an attractive eco-friendly alternative to other solvent. Also, engine tests indicated 5 wt % DEC in diesel fuel could reduce approximately 50% emissions [11]. Studies in which dialkyl carbonate has been used in the transesterification reaction are listed in Table 1.

The reaction between triglycerides and short-chain dialkyl carbonates could produce a mixture of fatty acid esters and fatty acid glycerol carbonate esters (FAGCs), and FAGCs continue to react with acyl acceptors in the same way to produce other molar fatty acid esters (FAEEs) and glycerol dicarbonate (GDC), which could be hydrolyzed into an eco-friendly chemical named glycerol carbonate (GC) (Fig. 2).

In a previous study, the thermal stability of fatty acid methyl esters (FAMEs) and the biodiesel prepared from various plants oil was investigated in supercritical methanol over a range temperatures and pressures between 270 °C/17 MPa and 380 °C/56 MPa [28]. Since most plants oil contain high amount of poly-unsaturated fatty acids, they tend to be vulnerable to thermal degradation at higher than 300 °C [29,30]. The second and third generation of biodiesel is produced from non-edible crops (i.e. vegetable and algal oil) and waste oil (i.e. waste animal oil and waste cooking oil) [7]. Jatropha, Simarouba, Neem, Rubber, and Karanja as a non-edible vegetable oil has been considered as a commercially viable alternative to edible oil for biodiesel production because of its physicochemical characteristics [31,32].

Multi-functionalized ILs have been found to be the best choice [33], owing to their solvation properties [34] and acidity/basicity of ILs can be tuned for specific applications by suitably choosing the cation/anion or its substitution pattern [35–37] as shown in Fig. 3. Transesterification is a cost-effective and an efficient process for producing biodiesel; it has been used for reducing the production

cost by using IL with dialkyl carbonates. IL catalysts have shown to higher catalytic activity than the acidic [38], basic, and enzymatic catalysts, although very few studies have reported the use of IL catalysts with DEC [39–41].

Similarly, Liang et al. [33] synthesized acidic-based solid IL polymers by coupling acidic IL oligomers with divinylbenzene. The synthesized IL was used as a catalyst for the transesterification of triglycerides in one-spot reaction, with a total biodiesel yield of 99%. The high acidity of the synthesized IL was attributed to its high hydrophobic surface area, acidity, and stability. The distance between the sulfonic acid groups in these ILs, which are the active sites for the transesterification reaction, can also influence the conversion. Furthermore, the large sized triglyceride molecules cannot access the acidic sites due to steric hindrance, thereby increasing the activation energy. Recently, Liu et al. [42] investigated that the mesoporosity of polymer ILs is thought to facilitate reagent access to internal active sites, enhancing performance. The successful use of non-edible oil as a feedstock with the polymer ILs offers a compelling way to bring down the total cost of biodiesel.

The catalytic activity of [PAMAM$_{3256}$ C$_{12}$] PIL was better than that of [IMHPS] [C$_{18}$]$_y$ PIL during the transesterification of P. chinensis oil (PCO) with DEC [14]. The reaction conditions for this process were optimized to yield 93% PCO-derived ethyl esters. The authors also compared the yield when synthesized PILs were used during a single transesterification reaction performed using DEC. The mild reaction conditions (1:5 M ratio of PCO:DEC), 300 wt % PIL loading, 120 °C, 400 rpm, and 6 h reaction time and the recyclability of [PAMAM$_{3256}$ C$_{12}$] allow sustainable synthesis of fatty acid esters in an eco-friendly and cost-effective manner. The activation energy for the first-order transesterification reaction was 4.862–14.885 kJ mol^{-1}, and providing an alternative route for the production of sustainable fuels. The authors also reported the production of biodiesel directly from the seeds of P. chinensis Bunge and J. curcus L. by using DEC. Jeon et al. [43] revealed some ILs that are efficient for the production of biodiesel from different feedstocks and acid-functionalized IL catalysts that have high activity for acid-catalyzed reactions.

The catalytic activity of IL catalysts and other catalysts such as Al–Zn-MCM-41-50 was compared during the transesterification of DMC with DEC. The reaction was performed at 125, 150, 175, and 200 °C with feed ratio of 1:1. Al–Zn-MCM-41-50 was found to be less active than IL catalysts for biodiesel production [44]. Yanfei et al. [45] also reported the methanolysis of soybean oil by using four ILs based on N, N, N-triethyl-N-propanesulfonic acid ammonium cation by using response surface methodology (RSM) based on the central composite rotatable design. The order of catalytic activity for the anions in the ILs was as follows: [H$_2$SO$_4$] > [p-CH$_3$C$_6$H$_4$SO$_3$] > [H$_2$PO$_4$] > [CF$_3$COO]. The highest yield was achieved with [(CH$_3$CH$_2$)$_3$N(CH$_2$)$_3$SO$_3$H][HSO$_4$] ILs than with acidic catalysts.
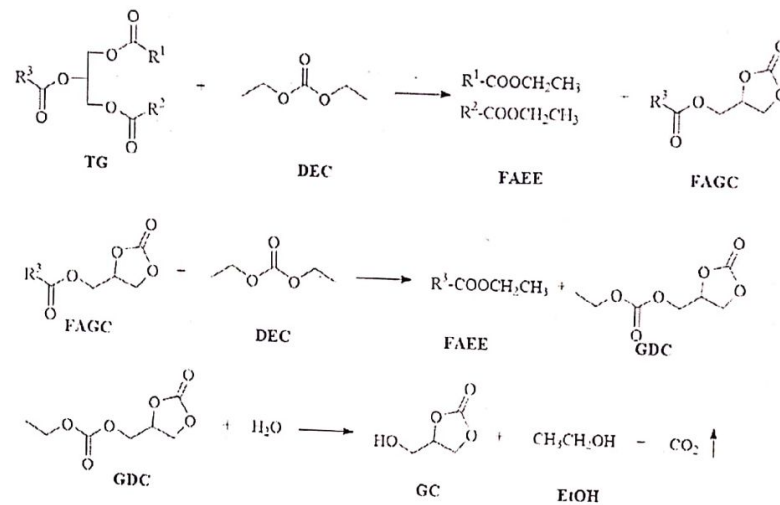
343

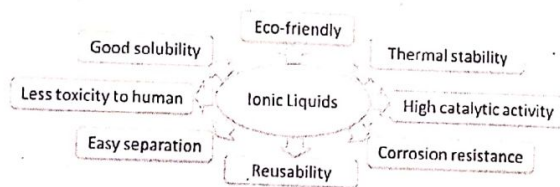Fig. 2. Production of ethyl esters by using transesterification of triglyceride and DEC.

Fig. 3. Applications of ionic liquid catalyst.

He et al. [46] synthesized and characterized a long-chain Brønsted acid IL, 3-(N,N-dimethyldodecylammonium) propane-sulfonic acid toluenesulfonate ([DDPA][Tos]) for synthesizing bio-diesel from free fatty acids (FFAs). A good yield (92.5–96.5%) of biodiesel product was obtained under the following optimum conditions: molar ratio of alcohols to FFAs of 1.5:1, mole fraction of IL at 10%, reaction temperature of 60 °C, and reaction time of 3 h. The long-chain Brønsted acidic IL showed good catalysis and could be recycled up to nine times. Moreover, Liu et al. [47] investigated the IL [HO_3S–$(CH_2)_3$–NEt_3]Cl–$FeCl_3$ containing both Brønsted and Lewis acidic sites for the synthesis of biodiesel from waste cooking oil. Because of the dual functionality of the IL, the yield of biodiesel was more than 95% at 120 °C for 4 h. Man et al. [48] used triethy-lammoniumhydrogensulfate (Et_3NHSO_4) as the pretreatment sol-vent, followed by KOH for the transesterification of crude palm oil. The biodiesel yield was 82.1% when only 5.2 wt % (with respect to reaction mixture) of Et_3NHSO_4 was used at 170 °C for 3 h. The end product obtained after KOH treatment was 96.9%.

Different base catalysts were analyzed for their biodiesel pro-duction potential by using dialkyl carbonate in the presence of CH_3OK, KOH, NaOH, CH_3ONa, and K_2CO_3 [49]. KOH and CH_3OK were found to be the most reactive catalysts for DMC-mediated trans-esterification reaction, affording yields of 92.0% and 93.8%, respectively. Despite being strong bases, CH_3OK, KOH, NaOH, CH_3ONa, and K_2CO_3 could only afford low yield of FAMEs, which might be partly attributed to their lower solubility in dialkyl car-bonate. However, the use of acid/base catalysts often leads to decay and emulsification problems and difficult purification and regen-eration [3,6,7]. Exposure to these chemicals should be avoided during biodiesel production [50–53]. In general, for industrial ap-plications, considerable efforts have been made to design acidic ILs

to replace homogeneous and heterogeneous acids in various chemical reactions [54].

Chlorometallate-based ILs have also been used as immobilizers for metal compounds such as zinc and tin complexes, which are the active catalyst precursors for the transesterification of soybean oil. DaSilveira et al. [40] immobilized the complex [Sn(3-hydroxy-2-methyl-4-pyrone)$_2$(H_2O)$_2$] in 1-n-butyl-3-methylimidazolium tet-rachloroindate ([BMI][InCl$_4$]). Zinc and Tin complexes have been shown to be more active than traditional catalysts in comparable acidic or basic conditions [55]. Furthermore, the disadvantage of using these complexes is that recovery is difficult and these cata-lysts cannot be reused as they are dissolved in the reaction medium.

The mixed-oxide catalyst with a molar ratio of 6:2:1 (Ca–La–Al) showed high catalytic activity for FAME synthesis (more than 90% of FAME was obtained). The catalyst also exhibited high stability and could be reused for up to five cycles with less than 5% yield reduction per cycle [56]. However, the disadvantage of using this mixed-oxide catalyst is the difficult to reaction oxidation.

Jechan et al. [57] introduced a sustainable approach to synthe-size biodiesel from vegetable oil and DMC via pseudo-catalytic transesterification on a maize residue biochar. The biodiesel yield reached up to 95.4% under the optimal operational conditions (380 °C and molar ratio of DMC to olive oil of 36:1). The biodiesel yield reached up to 95.4% under the optimal operational conditions (380 °C and molar ratio of DMC to olive oil of 36:1).

Li et al. [58] reported biodiesel production by using alkyl car-bonate and methanol with enzyme as a catalyst; the result sup-ported the use of alkyl carbonate for minimizing biodiesel production cost, as has been reported by some studies. The highest biodiesel yields of 92% and 94% were achieved under optimum conditions such as enzyme dosage of IUAI-ROL/g PCO, dialkyl car-bonate/methanol to oil molar ratio of 5:1, water content 20% by weight of oil, reaction temperature of 37 °C, and reaction time of 60 h. However, one of the common drawbacks associated with the use of enzymes for biodiesel synthesis is their weak operational stability, because of the rapid deactivation of the biocatalyst that impairs their exploitation at the industrial scale [59–61]. Recently, ILs have emerged as exceptionally non-aqueous green reaction media because of their unique solvent properties [62]. The use of ILs as reaction media for lipase-catalyzed biodiesel synthesis has also been reported [63].

The efficiency for the transesterification of triglycerides was

compared between enzyme catalysts and IL catalysts. A recent study showed ultrasound-assisted intensification of biodiesel synthesis from waste cooking oil by using methyl acetate and immobilized lipase obtained from *Thermomyces lanuginosus* (Lipozyme TLIM) as a catalyst. The system conditions for the ultrasound-assisted approach were oil-to-methyl acetate molar ratio of 1:9, enzyme loading of 3% (w/v), and reaction time of 3 h, and the biodiesel yield obtained under these conditions was 96.1% [64,65]. However, enzyme catalysts are more expensive, have limited regeneration and reuse potential, and require a long operating time [66]. Zulfiqar et al. [67] studied the enzymatic transesterification of *J. curcas* seed oil (JCSO), 6:1 of methanol: oil ratio and 0.5% water content, 10% nano-biocatalyst (Lipase-PDA-TiO$_2$ NPs) concentration at 37 °C for 30 h achieved biodiesel yield was 92%.

The reaction yields from enzyme-catalyzed transesterification are yet unfavorable compared to those obtained from IL-catalyzed reactions, and thus render the process impractical and uneconomical [68]. More active and stable catalysts can be produced by combining enzymes with imidazolium ILs [69] because ILs can protect the lipase from deactivation induced by methanol. When [BMIM]NTf$_2$ was used in combination with lipase for biodiesel production, the biodiesel yield was 96.3% from soybean oil [70,71].

Taken together, the results of these studies suggest that:

[•] ILs provide an ideal medium for the separation of biodiesel and removal of the glycerol carbonate by-product. However, long-term/or continuous biodiesel production systems based on ILs are lacking, and the accumulation of glycerol carbonate and recovery of ILs are likely to pose future challenges. Reusability is a very important aspect of ILs catalyst that can affect the cost and energy of the process by continuously recycling the catalyst. In addition, the environmental fate and any potential toxicity issues for most ILs are still largely unknown, only a few preliminary reports on their toxicological properties are available.

[•] DEC had higher efficiency of biodiesel production than methanol with enzyme catalyst. However, excess methanol leads to the inactivation of the enzyme, resulting in low enzymatic activity.

[•] The reaction yields from enzyme-catalyzed transesterification are yet unfavorable compared to those from IL-catalyzed reactions. Although further studies on the behavior of ILs structure should be carried out, the combination of biocatalysts and this clean separation methodology enhances the possibility of developing green industrial processes.

4. Cost effective co-product production by using DEC with various kinds of catalysts

GC is a potential substitute for several important expensive petroleum-derivative compounds used as surfactants, lubricants, and electrolytes, and components of CO$_2$ separation membrane and for polymer synthesis. Considering the efficiency, convenience, and ease of operation, transesterification of triglycerides with DEC and ILs is considered as the most prospective and simplest method for GC synthesis, unlike the reaction of triglycerides with DMC, and EC. To the best of our knowledge, the performance of IL catalysts has rarely been investigated with regard to the synthesis of GC in the presence of short-long chain alcohol (Table 2).

Folasegun et al. [72] investigated the GC production mechanism and showed that the utilization of dialkyl carbonates (such as DMC, DEC, and EC) in biodiesel production is an efficient way of producing GC as a by-product. TGs react with dialkyl carbonates to produce methyl carbonate diglycerides (MCDGs) and FAMEs, and

then MCDGs further react to produce dialkyl carbonate monoglycerides (DMCMGs) and FAMEs. Finally, DMCMGs rapidly undergo rearrangement to form a cyclic compound that further reacts with dialkyl carbonates to produce GC. Thus, the reaction between triglycerides and short-chain dialkyl carbonates produces FAGCs and GC (Fig. 2) [72].

When immobilized IL was used in the transesterification of glycerol with EC, 86% glycerol conversion was noted in 5 min accompanied with the generation of ethylene glycol with greater than 75% selectivity [73]. Most studies suggested that GC synthesis was efficient between 70 °C and 90 °C [73-75] when chemical catalysts were used and at 60 °C when biocatalysts with DMC were used [76-78]. GC is a green substitute for important petro-derivative compounds as ethylene carbonate or propylene carbonate [79]. The reactions involving hydrotalcite with DMC [80], and IL with DMC [81] require higher temperature of 100-120 °C.

Recently, Fan et al. [82] investigated the use of IL as a green solvent and catalyst. A new approach for producing glycerol-free biodiesel was developed using DMC catalyzed by sulfonated imidazolium ionic liquid (SIIL). The highest yield of FAMEs with the SIIL catalyst 1-propylsulfonate-3-methyl imidazolium hydrogen sulfate ([PrSO$_3$HMIM][HSO$_4$]) was 95.77% under the optimum conditions.

A copolymer of acidic IL oligomers and divinylbenzene (PIL) has also been used as a catalyst for the simultaneous (trans)esterification of FFA-containing triglyceride mixtures (waste cooking oil), possessing a high acid density of 4.4 mmol g^{-1}, high pore volume and surface area of 323 m^2 g^{-1}, and mean pore diameter of 35 nm [83]. The PIL copolymer was more active than the acidic IL alone, allowing 99% conversion of oleic acid with MeOH at only 1 wt % catalyst loading. PIL also achieved 99% yield in rapeseed transesterification with MeOH under the same reaction conditions and could convert high FFA content in waste cooking oil to biodiesel with 99% yield. The spent catalyst showed no structural changes or loss of acidic sulfur, and hence could be efficiently recycled with almost no loss in performance [84]. Hence, the development of a highly efficient and stable IL catalyst is important and desired for glycerol transesterification.

Homogeneous catalysts such as K$_2$CO$_3$; KOH; 1, 5, 7-triazabicyclo [4.4.0] dec-5-ene; and 1-*n*-butyl-3-methylimidazolium-carboxylate have high catalytic activities for GC production, but they are not preferable as they cannot be separated and reused easily [74,85,86]. Some heterogeneous catalysts [87], KNO$_3$/CaO [88], potassium fluoride-modified hydroxyapatite [89], LiNO$_3$/Mg$_4$AlO$_{5.5}$ [90], CaFeAl mixed oxide [91], and Mg/Al/Zr mixed oxides [92,93] have also been used for the transesterification process. However, most of these catalysts have drawbacks such as rapid deactivation, long reaction time, additional solvent requirement, and high reactant molar ratio. Pan et al. [81] used NaOH under different reaction conditions (70 °C for 2 h at a DMC/glycerol molar ratio and obtained 77% glycerol conversion and 23% GC selectivity.

Recently, GC production was formed when glycerol was reacted with DMC, DEC, and DBC in the presence of *Candida antarctica* lipase B (Novozym 435), by using tert-butanol as a solvent, 100% glycerol conversion was achieved after 12 h [94]. Conversion rates increased with alkyl chain length, with DMC, DEC, and DBC yielding 65%, 69%, and 79% conversion after 6 h, respectively. Similar result was reported by Lee et al. [95], who investigated whether Novozym 435 biocatalyst and silica gel could be reused by conducting repeated batch operation. GC was successfully synthesized with more than 90% conversion from DMC and glycerol with a molar ratio of 10 via Novozym 435-catalyzed transesterification at 70 °C for 48 h. This reaction uses with DEC and can produce high conversion rates in a short time.

Taken together, the findings of these studies suggest that:

Table 2
...reaction conditions and performance of various catalysts and dialkyl carbonate in glycerol carbonate.

Feedstocks	Catalyst	Solvent:Oil (mol/mol)	Reaction time (h)	Temperature (°C)	GC yield (%)	Refs
Glycerol	**Acid/base catalysts**					
Glycerol	NaOH					
Glycerol	H$_2$SO$_4$	5:1 (DMC:Oil)	1.5	75	98	[155]
Glycerol	MgO	5:1 (DMC: Oil)	1.5	75	80	[146]
Glycerol	CaO	2:1 (EC:Oil)	5	50	78	[142]
Glycerol	Metal oxides-hydrotalcite	2:1 (DMC:Oil)	0.2	60	93.5	[139]
Glycerol	k-Zeolite	4:1 (DMC:Oil)	2	70	77	[81]
Glycerol	Mg/Zr/Sr	3:1 (DMC:Oil)	1.5	75	95	[148]
Glycerol	LiNO$_3$/Mg$_4$AlO$_{5.5}$	3:1.1 (DMC:Oil)	1.5	90	56	[149]
Glycerol	K$_2$CO$_3$	3:1 (DMC:Oil)	1.5	80	96.24	[140]
Jatropha curcas	Al/Mg hydrotalcite	3:1 (DEC:Oil)	48	73	95	[151]
Glycerol	**Ionic liquids catalysts**	2:1 (EC:Oil)	5	50	82	[132]
Glycerol	[MHPS]x[C18]y					
Glycerol	1,3-Dichlorodistannoxanes	5:1 (DMC:Oil)	6	80	74	[10]
Glycerol	IL (BMIM$_2$-CO$_2$)	5:1 (DEC:Oil)	2	100	99.1	[152]
	IL [Mor$_{1,4}$][N(CN)$_2$]	3.2:1 (DMC:Oil)	1.33	74	93	[88]
Bio-glycerol residual oil	IL([TMA][OH])	3:1 (DMC:Oil)	13	120	95	[143]
Bio-glycerol residual oil	**Enzyme catalysts**	3:1 (DMC:Oil)	1.5	80	95	[144]
Bio-glycerol residual oil	Enzyme biocatalyst					
Soybean oil	Enzyme biocatalyst	10:1 (DMC:Oil)	6	60	90	[145]
Glycerol	Enzyme biocatalyst	10:1 (DEC:Oil)	6	60	95	[143]
P. chinensis oil	Novozym 435	10:1 (DBC:Oil)	6	60	92	[145]
Rapeseed oil	Guanidine IL	6:1(Tert-butanol:Oil)	6	60	92	[154]
Palm oil	[PEI$_{10000}$C$_{12}$] PIL	1:0.025 (DMC:Oil)	5	80	95.5	[147]
Glycerol	Sulfonated imidazolium IL	5:1 (DEC:Oil)	1.5	120	95	[14]
	Immobilized-lipase	5:1 (DMC:Oil)	6	110	70	[62]
	Ca(C$_3$H$_7$O$_3$)$_2$	10:1 (DMC:Oil)	5	55	80	[145]
		2.5:1 (DMC:Oil)	3	60	95	[149]

[•] The use of IL during transesterification yields better results than when other homogenous, heterogeneous, and enzyme catalysts are used. Recently, more attention has been paid to ILs as green solvents due to their low volatility, vapor pressure, flammability, and environmental advantages.

[•] Heterogeneous catalysts are not suitable for GC production owing to drawbacks such as deactivation, long reaction time, additional solvent requirement, and high reactant ratio. Furthermore, homogeneous catalysts are not preferable as they cannot be separated and reused easily.

5. Kinetic study and activation energy of biodiesel production by using DEC with ILs

The kinetic study of transesterification with the methylating agent, dialkyl carbonate has not been widely investigated. Therefore, in this review, IL reaction system consisting of triglycerides and dialkyl carbonate for the production of biodiesel is described. Catalysis is among the most active research fields as it attempts to reduce the quantity of materials and activation energies required and can accomplish many of the objectives of biodiesel. Catalytic reactions have additional positive implications, such as catalyst recovery from the final reaction mixture to increase reusability throughout several recycles [96].

Few studies have investigated the kinetics of triglycerides during dialkyl carbonate reactions, and the first-order transesterification of triglycerides was found to be the best kinetics mechanism. The kinetics of triglycerides were determined when Rathore et al. [23] estimated activation energy (Ea) was of the order of 38.0 ± 2 and 35.5 ± 2 kJ mol^{-1} for DMC, and 40.4 ± 2 and 38.2 ± 2 kJ mol^{-1} for DEC, for the conversion of *J. curcas* and *P. pinnata* oil, respectively. Notably, the activation energy for supercritical DMC was slightly lower than that for supercritical DEC. The summary of the kinetics investigated is shown in Table 3.

The reported activation energy for non-catalytic supercritical transesterification varied with different reaction conditions and natures of oil [97]. Non-catalytic transesterification necessitates high activation energy (117 kJ mol^{-1}, 128 kJ mol^{-1}, or 29 kJ mol^{-1}), whereas non-catalytic supercritical transesterification requires less activation energy (9–65 kJ mol^{-1}) owing to the change in the polarity of the reactant under supercritical condition. Pan et al. [98] specified the efficient activation energy (83.56 kJ mol^{-1}). Under mild reaction conditions, one-pot conversion of non-edible *Firmiana platanifolia* L. oil into biodiesel was possible by using inexpensive, scalable imidazolium salt-based solid Brønsted acid-Lewis acid bifunctional catalyst ([DSI][FeCl$_4$]). The [DSI][FeCl$_4$] catalyst exhibited excellent catalytic performance, and kinetic studies showed that the catalytic process followed the first-order kinetics. Long-chain PILs have recently been used as a new generation of ionic solvents, considering that several long-chain PILs have an amphiphilic nature and thus represent a new class of cationic surfactants with peculiar properties [99].

Recently, catalysts obtained from *Thevetia peruviana* sources have been used in the transesterification with DMC. Panchal et al. [100] investigated the kinetic transesterification with DMC (molar ratio, 1:4) and prepared a CH$_3$OK alkali catalyst: the activation energy for the conversion of TG to MG ranged from 10.752 to 32.817 kJ mol^{-1}. The transesterification of *T. peruviana* oil to DMC-esters (DMC-TP-BioDs) proceeds via the first-order mechanism. The use of CH$_3$OK catalyst for transesterification oxidation obtained this disadvantage of CH$_3$OK catalyst.

Islam et al. [101] determined the activation energy for the second-order reaction between DMC and canola oil when triazabicyclodecene was used as a catalyst. They found that the activation energy was significantly reduced and the progress of the reaction was expedited using the basic triazabicyclodecene catalyst and DMC. A kinetic model based on the triazabicyclodecene-catalyzed transesterification reaction of canola oil was developed using an oil/DMC molar ratio of 1:3, catalyst concentration of 1.5 wt % based on oil weight, and temperatures of 50, 60, and 70 °C. The activation energy of the second-order reaction was 36.4 kJ mol^{-1}, and the rate constants were 1.09×10^{-2}, 1.65×10^{-2}, and 2.39×10^{-2} kJ mol^{-1} min^{-1} at 50, 60, and 70 °C, respectively. The

Table 3
Summary of kinetic study using DEC and DMC.

Feedstock	Catalyst type	Solvent:Oil (mol/mol)	Activation energy (kJ mol^{-1})	Yield (%)	Refs
Supercritical transesterification					
Jatropha curcas oil	--	40:1(DMC:Oil)	35.5 to 38.0	92	[ ]
Pongamia pinnata oil	--	40:1 (DEC:Oil)	38.2 to 40.4	94	[ ]
Schizochitrium limacinum	--	10:1 (MeOH:Oil)	54	86	[ ]
Schizochitrium limacinum	--	10:1 (DMC:Oil)	56.6	83	[ ]
Non-supercritical transesterification					
Alkaline					
Glycerol	CH$_3$OK	3:1.5 (EC:Oil)	58.7	--	[ ]
Thevetia peruviana oil	CH$_3$OK	4:1 (DMC:Oil)	10.752 to 32.817	97.5	[ ]
Waste frying oil	CaO	5:1 (MeOH:Oil)	78.8	--	[ ]
Canola oil	C$_7$H$_{13}$N$_3$	3:1(DMC:Oil)	36.4	84	[ ]
Palm oil	KOH	6:1 (DMC:Oil)	79.1	98	[ ]
Oleic Acid	NbOPO$_4$	5:1 (DMC:Oil)	62.17	97.99	[ ]
Acidic					
Yellow grease	CH$_3$SO$_3$H	5:1(DMC:Oil)	1.99	94	[ ]
Ionic liquid					
Oleic Acid	MMFP-IL	12:1 (MeOH:Oil)	35.3	95	[ ]
Pistacia chinensis oil	[PEI$_{1000}$C$_{12}$]	5:1 (DEC:Oil)	4.862 to14.885	93	[ ]
Tung nut oil	Acidic PILs	1.5:1 (MeOH:Oil)	12.81	91	[ ]
Jatropha curcas oil	[IMHPS]$_x$ [C$_{18}$]$_y$ PILs	5:1 (DMC:Oil)	15.382	94	[ ]
Enzyme					
Palm oil	Lipozyme TL IM	3:1 (Oleyl alcohol:Oil)	16.85	79.54	[ ]
Palm oil	lipase Novozyme 435	4:1 (DMC:Oil)	26	90	[ ]
Waste cooking oil	Lipase 435	6:1 (DMC:Oil)	18.96	--	[ ]

Where, - is not measured

activation energy for the transesterification of oil with methanol as the base catalysts was in the range of 33.6–84 kJ mol^{-1}. The activation energy obtained (36.4 kJ mol^{-1}) with the basic triazabicyclodecene catalyst and DMC as the acyl acceptor was in agreement with the reported range.

Recently, Alessio et al. [102] evaluated whether commercial niobium phosphate can be used as a heterogeneous catalyst in biodiesel production from oleic acid and low-cost raw materials by using DMC as the acyl receptor. He discussed pseudo-homogeneous first-order reaction inforward and backward directions for the esterification of oleic acid. The activation energy (Ea) and pre-exponential factor (k$_0$) were estimated to be 62.17 kJ mol^{-1} and 1.816 × 10^{-6} for the forward direction, and 77.75 kJ mol^{-1} and 1.816 × 10^{-6} for the reverse direction, respectively. The activation energy obtained for the conversion of TG to DECMG ranged from 4.862 to 14.885 kJ mol^{-1}.

Rathnam and Madras [104], investigated the kinetics of biodiesel production from *Schizochytrium limacinum* microalgae by using three methylating agents, that is, methanol, DMC, and methyl acetate. The reactions were conducted at 518–643 K at 20 MPa and methylating agent to S. limacinum microalgae ratio of 10:1. The reaction time was varied between 10 and 80 min. The rate constant (k) obtained using pseudo first-order kinetics followed an order of k$_{methanol}$ > k$_{dimethyl\ carbonate}$ > k$_{methyl\ acetate}$, whereas the activation energy (E) for the three systems followed a trend of E$_{methyl}$ $_{acetate}$ > E$_{dimethyl\ carbonate}$ > E$_{methanol}$. The authors reported that the activation energy was the highest at 62.7 kJ/mol for the methyl acetate system, followed by that for DMC (56.6 kJ mol^{-1}) and methanol systems (54.0 kJ mol^{-1}) [103].

Sun et al. [104] reported the kinetics of the transesterification of palm oil and DMC for biodiesel production during the catalysis of immobilized lipase Novozyme 435. The relationship between the initial reaction rate and temperature was determined, and the activation energy was obtained, based on the Arrhenius law. The value of E$_a$ was 26.0 kJ mol^{-1}. The effect of palm oil concentration was investigated over the range of 30–700 mmol/L by maintaining the catalyst amount (5–75 mg/mL). The optimal temperature was 55 °C, indicating that the transesterification kinetics of palm oil and

DMC was in agreement with the ordered bi-bi mechanism [104].

The use of waste cooking oil and DMC as the reactants and lipase-435 enzyme as the catalyst reduced the cost of the reaction run for 4 h, with activation energy of FAME production of about 18.96 kJ mol^{-1} [105]. Similarly, Rejasse et al. [106], performed an energy and thermodynamic study by using enzymatic biodiesel synthesis from palm oil and showed that the activation energy of monoglyceride to FAME formation was between 17.78 and 23.35 kJ mol^{-1}.

Esteban et al. [107] investigated the transesterification of glycerol with DMC and EC and CH$_3$OK used as a catalyst. The kinetic study was performed under mild operation conditions: temperature (50–70 °C by using DMC; 40–60 °C by using EC), molar excess of organic carbonate to glycerol (1.5–3), and low catalyst loads (1000–2500 ppm for DMC; 50–150 ppm for EC). During the reaction with DMC, the model contemplates an irreversible reaction with activation energy of 28.4 ± 1.5 kJ mol^{-1} and deactivation constant of 0.03 ± 0.01 min^{-1}. When EC is used, the activation energy was 83.0 ± 1.6 kJ mol^{-1} and 58.7 ± 11.4 kJ mol^{-1} for the direct and reverse reactions, respectively, and the deactivation constant was 0.11 ± 0.02 min^{-1}.

Comparisons of the produced activation energies employing homogeneous and heterogeneous catalyst methods have been reported. Many researchers have used homogeneous alkali catalysts such as sodium hydroxide and potassium hydroxide to develop processes for the activation energies. Owing to the low cost; these catalysts are the most commercialized [108]. Deshmane and Adewuyi [109], and Birla et al. [110] reported catalytic transesterification; homogeneous catalytic reaction necessitates less activation energy, 26–83 kJ mol^{-1}, unlike >79 kJ mol^{-1} required for the heterogeneous catalytic reaction. Berrios et al. [111] also obtained activation energy values of 50.7 and 44.5 kJ mol^{-1} for forward reaction and 31.01 and 42.76 kJ mol^{-1} for the reverse reaction catalyzed by 5% and 10% sulfuric acid, respectively. The activation energy values for transesterification reaction are generally higher than those of esterification reactions (54.6–79.1 kJ mol^{-1}). Li et al. [112] determined the effective activation energy for biodiesel production from *Camptotheca acuminata* seed oil catalyzed by novel

Bronsted–Lewis acidic IL [BSO₃HMIM]HSO₄–Fe₂(SO₄)₃ catalyst. A high conversion yield (95.7%) and activation energy of 37.68 kJ mol⁻¹ were obtained in 60 min under relatively low temperature of 60 °C. The Bronsted–Lewis acidic IL [BSO₃HMIM] HSO₄–Fe₂(SO₄)₃ catalyst exhibited excellent catalytic performance compared to homogeneous and heterogeneous catalysts. Acidic ILs are the new type of catalysts with high-density active sites as liquid acids, but non-volatilization as solid acids. Furthermore, cations and anions of ILs can be designed to bind a series of groups with specific properties, in order to regulate the acidity. Recently, they have been used to replace traditional liquid acids such as sulfuric acid and hydrochloric acid for biomass conversion [113,114].

Pan et al. [115] investigated the activation energy by using the 4 wt % acidic IL-functionalized mesoporous melamine-formaldehyde polymer (MMFP-IL) dosage at 90 °C for 3 hands MeOH to oleic acid mole ratio of 12:1. Kinetic analysis indicated that the reaction obeyed first-order reaction kinetics and activation energy (Ea = 35.3 kJ mol⁻¹) was relatively lower than that reported previously. The outstanding catalytic performances of ILs could be ascribed to their remarkable properties such as strong acidity, high acid sites, and high oxidation stability [116].

The following conclusions can be drawn from the analysis of the different experimental results:

- [•] Synthesized activation energy by using dialkyl carbonate was more effective than that using other solvents such as methanol and butanol.
- [•] The use of IL for the transesterification process produced activation energies that were better than those produced when other homogenous, heterogeneous, and enzyme catalysis were used.
- [•] IL catalysts have more advantages than other catalysts. The activation energy was found to be excellent when dialkyl carbonate and waste oil with ILs was used. Therefore, the transesterification of dialkyl carbonate and waste oil with ILs can provide a sustainable alternative fuel in the future.

6. Environmental considerations of biodiesel produced from dialkyl carbonate by using ILs

Transesterification of oil with short-chain alcohols seems a simple and fascinating way to produce biodiesel with good viscosity. The usage of short-chain alcohols may also have some advantages such as higher reaction activity [117]. The effect of long-chain alcohols and triglycerides has been investigated [118,119]. The physical properties of biodiesel are shown in Table 4.

The major disadvantages of biodiesel are higher viscosity, lower energy content, higher NO$_x$ emissions, lower engine speed and power, injector coking; engine compatibility, higher price, and higher engine wear [120]. These problems have been addressed by using biodiesel especially that prepared from dialkyl carbonate with ILs, such as that with no sulfur and NO$_x$ emissions [14]. The alarming rate of increase in atmospheric CO$_2$ level can be relieved, to a certain extent, by using biodiesel usage, thereby mitigating the effects of global warming. Biodiesel usage could help reduce CO$_2$ emissions into the atmosphere over its life cycle [121]. Takase et al. [31] undertook theoretical and experimental studies to investigate the performance and exhaust characteristics of Neem, Jatropha and Karanja biodiesels, study indicated that CO, NOx, HC and smoke emission could reduce to 18%, 3%, 18% and 12% respectively for Neem biodiesel when compared to fossil diesel. Similarly, a study on comparison of life-cycle greenhouse gas (GHG) emissions showed a 55% reduction relative to conventional jet fuel, with emission of 40 kg CO$_2$ eq/GJ of fuel produced from Jatropha [122].

Kinematic viscosity has an important impact on fuel injection and combustion. It is an index expressing the stickiness of a fuel. Kinematic viscosity needs to be regulated within in a safety range of 3.5–5 mm²/s and 1.9–6 mm²/s according to the EN14214 and ASTMD6752 regulation, respectively. Recently, Panchal et al. [14] reported that biodiesel production catalyzed by novel [PEI₁₀₀₀C₁₂] PIL with DEC proved was an efficient and environmentally friendly technology. Biodiesel produced from R. chinensis oil with DEC has greater kinematic viscosity of 4.1 mm²/s, specific gravity of 0.86 g/cm³, and acid value of 0.31 mgKOH/g, which meets the ASTM standard. Similarly, Panchal et al. [123] investigated the production of biodiesel from yellow grease with DMC and methanesulfonic acid (CH₃SO₃H) as a catalyst. The properties of biodiesel, such as kinematic viscosity, were found to be 1.56 mm²/s, and specific gravity was found to be 0.87 g/cm³. Panadare et al. [103] compared the use of ILs and enzyme catalysts, and obtained moderate kinematic viscosity of 3.85 mm²/s, under parameter conditions such as waste cooking oil and DMC as reactants and Lipase-435 enzyme as the catalyst.

Another study by Biodiesel Emission [124] showed that the level of polycyclic aromatic hydrocarbons (PAHs), which have been identified as potential cancer-causing compounds, also decreased by 80% in biodiesel emission. In addition, expanded biodiesel use wouldenormously contribute to environmental protection, energy saving and economic development.

In general, methyl esters have higher flash point (FP) than diesel, which is usually around 100 to 180 °C, whereas conventional FP for diesel fuel is only 55 to 66 °C, admirable biodegradability and lubricity, and higher combustion efficiency compared to the corresponding properties of petro-diesel [125]. The biodiesel was characterized by the physical properties of the produced methyl esters, such as the FP of fried soybean oil methyl esters was found to be 100 °C, density was 0.86 g/cm³, cloud point (CP) was 6 °C, pour point (PP) was −5 °C, and kinematic viscosity was 3.93 mm²/s. Thus, methyl esters are safe for transport, handling, and storage purpose [126]. This high FP of biodiesel is attributed to the presence of a predominantly unsaturated acid chain length of C18:1 and C18:2 in the vegetable oil [127].

Few researchers have used DEC for biodiesel production and have found zero sulfur and reduced emission of CO₂. Biodiesel has higher cetane number than diesel fuel because of its long-chain fatty acids with 2–3 double bonds; it is without aromatics and contains 10–11% oxygen by weight. Biodiesel produced using DEC has more oxygen content than others produced using solvents such as methanol [13]. These characteristics of biodiesel reduce the emission of CO₂, HC, and particulate exhaust gases compared to those emitted by diesel fuel. Conventional fuel contains more sulfur and thus damages the atmosphere by releasing SO₂. However, biodiesel synthesized using DEC has almost zero sulfur content [4].

Biodiesel has many promising characteristics, including reduced exhaust emission [128]. The economic advantages of biodiesel are that it reduces greenhouse gas emission, helps reduce a country's reliance on crude oil imports, and supports agriculture by providing new labor and market opportunities for domestic crops. The corrosion behavior of Co (salophen) catalyst and DEC to a stainless steel reactor and the corrosion rate to stainless steel by using Co catalyst was shown to be below 0.005 mm/a [13].

The acidic value suggests that conversion is better by using DMC with ILs than by using DMC with CH₃ONa. Gardy et al. [129] also reported the synthesis of a novel magnetic SO₄/Fe–Al–TiO₂ solid acid catalyst for biodiesel production via the transesterification of waste cooking oil. The physical characteristics of biodiesel conformed to ASTM and EU standards, with a cloud point of −11.3 °C. Decomposition or combustion of synthetic biodiesel occurred at >144 °C and was complete at 226 °C. Transesterification conditions

Table 4

Fuel properties produced using DEC, DMC, and DEC/DMC compared with ASTM 6751-02 and EN14112.

Feedstocks	Catalyst	Solvent:Oil (mol/mol)	Kinematic viscosity (mm^2/s)	Specific gravity (g/m^3)	Acid value (mgKOH/g)	Flash point (°C)	Cloud point (°C)	Pour point (°C)	Refs
Supercritical method									
Rapeseed oil	—								
Soybean oil	—	41:1(DMC:Oil)	4.3	—	0.14	—	—	—	[18]
		40:1(MeOH:Oil)	5.1	0.89	0.5	—	—	—	[20]
Non-Supercritical method									
Alkaline									
Palm oil	KOH								
Palm oil	KOH	2:1(DMC:Oil)	4.5	0.87	0.065	—	—	—	[110]
		14:1(DEC/DMC:Oil)	4.6	0.88	0.064	—	—	—	[116]
Pongamia pinnata oil	KOH	3:1(DMC:Oil)	5.2	0.89	0.28	122	5	3	[153]
Soybean oil	CH_3OK	9:1(DMC:Oil)	4.4	0.896	0.5	—	—	—	[72]
Waste cooking oil	Calcined Mg/Al HT	4:2(MeOH/EtOH:Oil)	3.7	0.84	0.05	—	—	—	[155]
Thevetia peruviana oil	CH_3OK	4:1(DMC:Oil)	3.99	0.87	0.2	135	9	−3	[150]
Acidic									
Fried soybean oil	KBr	4:1(DMC:Oil)	3.93	0.86	0.26	148	4	1	[10]
Yellow grease	CH_3SO_3H	5:1(DMC:Oil)	1.56	0.87	0.5	100	6	−5	[121]
Schizochytrium limacinum	CH_3SO_3H	4:1(DMC:Oil)	3.87	0.856	0.3	115	1	−2	[152]
Schizochytrium limacinum	CH_3ONa-treated algae	4:1(DMC:Oil)	3.69	0.82	0.4	130	7	−2	[156]
Schizochytrium limacinum	CH_3SO_3H	4:1(DMC:Oil)	3.87	0.856	0.3	115	1	−2	[99]
Ionic liquid									
Pistacia chinensis	$[PEI_{10000}C_{18}]$ PILs	5:1(DEC:Oil)	4.1	0.86	0.31	103	1	−1	[12]
Jatropha curcas	[IMHPS] $[C_{18}]_y$ PIL	5:1(DMC:Oil)	4.12	0.851	0.312	110	2	−4	[131]
Yellow grease	Superhydrophobic porous poly-PIL	21.9:1(MeOH:Oil)	4.1	0.87	0.16	—	—	—	[157]
Schizochytrium limacinum	[BSMBIM] $[CF_3SO_3]$ IL	12:1(MeOH:Oil)	4.94	0.88	0.45	161	—	—	[158]
Soybean seed oil	p-toluene sulfonate [DDPA] [Tos]	2:1 (MeOH:Oil)	4.12	0.86	0.31	148	4	1	[124]
Tung nut seed oil	Acidic-PILs	1.5:1 (MeOH:Oil)	4	0.85	0.3	150	−2	−4	[152]
Jatropha curcas	[IMHPS] $[C_{18}]_y$	5:1(DMC:Oil)	3.9	0.851	0.31	110	2	−4	[131]
Enzymatic									
Waste cooking oil	Lipase–435	6:1(DMC:Oil)	3.85	0.882	0.41	—	—	—	[104]
Soapstocks oil	5% Novozym 435	3:1(DEC:Oil)	4.2	0.87	0.5	—	—	—	[15]

Where, - is not measure.

were as follows: methanol: WCO molar ratio of 10:1, and 2.5 h of reaction time at 90 °C by using 3 wt % of the $SO_4/Fe–Al–TiO_2$ catalyst.

Two important parameters for low-temperature applications of a fuel are CP and PP. The CP is the temperature at which wax first becomes visible when the fuel is cooled. The PP is the temperature at which the amount of wax from a solution is sufficient to gel the fuel; thus, it is the lowest temperature at which the fuel can flow. Biodiesel has higher CP and PP than conventional diesel.

Taken together, the results of these studies suggest that:

[•] CO, CO_2, NO_x, and sulfur emissions decrease with the use of dialkyl carbonate and waste oil with ILs. CO emission decreases by about 4–55.76% depending on different conditions.

[•] Biodiesel synthesized using DEC with waste oil and ILs has reduced emission of hydrocarbon and almost zero sulfur content.

[•] Biodiesel synthesized using DEC has more oxygen content than that synthesized using other solvents.

[•] Considering all factors, IL catalysts has more advantages than other catalysts. ILs and DEC with waste oil are environmentally friendly and promising acid processes for biodiesel synthesis. Biodiesel fuel properties vary depending on the

solvent and catalyst and the biodiesel conversion process. Most reviewed biodiesel fuels have excellent kinematic viscosity; they are manufactured using dialkyl carbonate and waste oil with ILs. However, the viscosity, density, FP, CP, and PP ranges of biodiesels are close to those of diesel fuel. Therefore, transesterification of dialkyl carbonate and waste oil with ILs can ensure sustainable alternative fuel in the future.

7. Future direction of biodiesel production

The issues of environmental and energy security are fundamental challenges of the 21st century. Dependence on conventional fossil fuels is leading to global warming and possible major disruptions in social structures [37]. Therefore, World are trying to find environmentally begin alternative to harmful chemical. In view of that, DEC has become the target of interest for many researchers studying biodiesel production because of their advantages and environmentally friendly nature. Advancements in green synthesis methods will be key to the future success of ILs chemistry and its suitability to environmental fields. Facile control over the basic properties ILs (e.g., pore size, high surface area, and functional groups) can expand their environmental applicability in various

respect(s). This review suggests that non-edible oil or waste oil and DEC with IL catalyst is a promising process that can sustain biodiesel growth. However, the future of the non-edible biodiesel will also depend upon the establishment of low-cost and competent biodiesel production technologies. Using waste oil as raw material to produce biodiesel can not only solve the debate between fuel and food, but also solve some problems in waste oil disposal.

As the cost of biodiesel production is a major concern nowadays, the recyclability of IL catalysts used in the biodiesel process should be taken into account. Recycling of ILs reduces the cost of biodiesel production. To date, they are currently unused in industrial applications; expensive, and in a negative aspect for their treatment after usage prior to disposal [159]. The high thermal stability and non-volatility properties of ILs have somehow suggested potential problems with persistence to the environment. Hence, there are some key challenges to be addressed in future research. (1) Future needs to research activities are in progress to identify cost effective such as feedstock and biodiesel process. (2) The next generation of ILs should be made cheaper, stability, recyclable, and eco-friendly. (3) This can be achieved by preventing ILs from leaching off the carriers and loss of activity caused by the alcohol and stirring force. With the impending commercial availability of the economically feasible future generation biodiesel, this fuel should remain as a substitute to fossil fuel that can potentially satisfy mid-term energy needs to form part of the total solution to worldwide energy and environmental woes.

8. Conclusions

With swelling population and industrial development, the demand for energy will see multifold increases in the future. IL-catalyzed production of biodiesel has attracted remarkable attention recently, owing to the merits such as mild reaction conditions, environmental friendliness, and reusability. The feedstock type is one of the most important parameters in biodiesel production which covers the production cost. Similarly, studies have shown that the greenhouse gases emission ratio of waste oil biodiesel is better than natural oil and other biodiesel; making it more sustainable energy source. This technique shows remarkable potential for industrial-scale production of biodiesel. Various approaches have been developed for ILs; nevertheless, only a few of them seem to be economically feasible. Most of the commercial ILs are prepared using polymeric materials, because this process is simple, and the carrier development is a cost-effective process. However, the stability of ILs needs to be enhanced.

IL catalysts have been shown to produce high yields and mild reaction conditions comparable with those when homogeneous, heterogeneous, and enzyme catalysis is used; moreover, IL catalysts can be easily separated from the reacting mixtures for recycling. In addition, the formed biodiesel product is expected to be superior in quality in terms of lubricity, oxidation stability, density, kinematic viscosity, cetane number, and acid value.

Among the cited ILs with DEC, we consider that salts with Brønsted acidity or basicity are especially interesting because, in addition to a low risk of environmental contamination, they allow high conversion yields of vegetable oils and animal fats to biodiesel in a short time with mild reaction conditions. In addition, Brønsted acidic ILs can be used in the conversion of both FFAs and triglycerides to biodiesel without the need of pretreatment of the oil for moisture removal. This feature facilitates biodiesel production and reduces process costs, making them promising candidates in the production of biodiesel.

Declaration of competing interest

This manuscript has not been published or presented elsewhere in part or in entirety and is not under consideration by another journal. We have read and understood your journal's policies, and we believe that neither the manuscript nor the study violates any of these. There are no conflicts of interest to declare.

References

[1] M.A. Mujtaba, M.C. Haeng, H.H. Masjuki, M.A. Kalam, H.C. Ong, M. Gul, M.H. Harith, M.N.A.M. Yusoff, Critical review on sesame seed oil and its methyl ester on cold flow and oxidation stability, Energy Rep. 6 (2020) 40–54, https://doi.org/10.1016/j.egyr.2019.11.160.

[2] S. Rezania, B. Oryani, J. Park, B. Hashemi, K.K. Yadav, E.E. Kwon, J. Hur, J. Chao, Review on transesterification of non-edible sources for biodiesel production with a focus on economic aspects, fuel properties and by-product applications, Energy, Convers. Manage. 201 (2019) 112155, https://doi.org/10.1016/j.enconman.2019.112155.

[3] J. Hongsub, L. Youngrak, K. Daeheum, O.H. Sung, W.K. Seung, L. Jinwon, H.K. Yong, P. Chulhwan, Enzymatic production of glycerol carbonate from by-product after biodiesel manufacturing process, Enzyme Microb. Technol. 51 (2012) 143–147, https://doi.org/10.1016/j.enzmictec.2012.05.004.

[4] D. Babu, V. Thangarasu, A. Ramanathan, Artificial neural network approach on forecasting diesel engine characteristics fuelled with waste frying oil biodiesel, Appl. Energy 263 (2020) 114612, https://doi.org/10.1016/j.apenergy.2020.114612.

[5] C. Albert, P. Jyun-Hong, L. Nien-Chu, T. Ming-Chieh, M. Takehisa, T. Makoto, C. Shih-Yuan, Y. Chia-Min, Efficient simultaneous esterification/transesterification of non-edible Jatropha oil for biodiesel fuel production by template-free synthesized nanoporous titanosilicates, Catal. Today 356 (2020) 56–63, https://doi.org/10.1016/j.cattod.2019.10.006.

[6] A.M. Ashraful, H.H. Masjuki, M.A. Kalam, I.M. Rizwanul Fattah, S. Imtenan, S.A. Shahir, H.M. Mobarak, Production and comparison of fuel properties, engine performance, and emission characteristics of biodiesel from various non-edible vegetable oils: a review, Energy Convers. Manage. 80 (2014) 202–228, https://doi.org/10.1016/j.enconman.2014.01.037.

[7] S. Rezania, Z.S. Korrani, M.A. Gabris, J. Cho, K.K. Yadav, M.M.S. Cabral-Pinto, J. Alam, M. Ahamed, H.R. Nodeh, Lanthanum phosphate foam as novel heterogeneous nanocatalyst for biodiesel production from waste cooking oil, Renew. Energy 176 (2021) 228–236, https://doi.org/10.1016/j.renene.2021.05.060.

[8] S. Pinzi, I.L. Garcia, F.J.L. Gimenez, M.D.L. Castro, G. Dorado, M.P. Dorado, The ideal vegetable oil-based biodiesel composition: a review of social economical and technical implications, Energy Fuel 23 (2009) 2325–2341, https://doi.org/10.1021/ef801098a.

[9] G. Pradhan, Y.C. Sharma, Studies on green synthesis of glycerol carbonate from waste cooking oil derived glycerol over an economically viable NiMgOx heterogeneous solid base catalyst, J. Clean. Prod. 264 (2020) 121258, https://doi.org/10.1016/j.jclepro.2020.121258.

[10] B. Panchal, S.J. Qin, T. Chang, Y.Z. Sun, J.X. Wang, K. Bian, Production of methyl esters from fried soybean oil using dimethyl carbonate with hydrobromic acid, Energy Rep. 5 (2019) 1463–1469, https://doi.org/10.1016/j.egyr.2019.10.007.

[11] D.J. Zhu, F.M. Mei, L.J. Chen, W.L. Mo, T. Li, G.X. Li, An efficient catalyst Co (salophen) for synthesis of diethyl carbonate by oxidative carbonylation of ethanol, Fuel 90 (6) (2011) 2098–2102, https://doi.org/10.1016/j.fuel.2011.02.024.

[12] B. Panchal, T. Chang, Y.H. Kang, S.J. Qin, Q.J. Zhao, J.X. Wang, K. Bian, Y.Z. Sun, Synthesis of polymer based catalyst: optimization and kinetics modeling of the transesterification of Pistacia chinensis oil with diethyl carbonate using acidic ionic liquids, Fuel 276 (2020) 118121, https://doi.org/10.1016/j.fuel.2020.118121.

[13] H.S. Gao, C. Guo, J.M. Xing, J.M. Zhao, H.Z. Liu, Extraction and oxidative desulfurization of diesel fuel catalyzed by a Brønsted acidic ionic liquid at room temperature, Green Chem. 12 (2010) 1220–1224, https://doi.org/10.1039/c002108c.

[14] Y.Y. Jiang, H.S. Xia, C. Guo, I. Mahmood, H.Z. Liu, Enzymatic hydrolysis of penicillin for 6-apa production in three-liquid-phase system, Appl. Biochem.

Biotechnol. 144 (2010) 145–149, https://doi.org/10.1007/s12010-007-8013-x.

[15] Y. Bian, J. Zhang, S. Zhang, C. Liu, D. Zhao, Synthesis of polymeric liquid by phenolic condensation and its application in esterification, ACS Sustain. Chem. Eng. 7 (20) (2019) 17220–17226, https://doi.org/10.1021/acssuschemeng.9b03859.

[16] I. Guiju, H. Zile, G. Zhe, Z. Yan, C. Yu, S. Zhu, Z. Lingxia, S. Jianlin, KF-loaded mesoporous Mg–Fe bi-metal oxides: high performance transesterification catalysts for biodiesel production, Chem. Commun. 49 (2013), https://doi.org/10.1039/C3CC44964E, 8006–8008.

[17] R. Tania, S. Shalini, Y.C. Sharma, Study on kinetics-thermodynamics and environmental parameter of biodiesel production from waste cooking oil and castor oil using potassium modified ceria oxide catalyst, J. Clean. Prod. 247 (2020) 119166, https://doi.org/10.1016/j.jclepro.2019.119166.

[18] X. Chunli, S. Jun, Z. Binbin, L. Qiang, On the study of KF/Zn(Al)O catalyst for biodiesel production from vegetable oil, Appl. Catal. B Environ. 99 (2010) 111–117, https://doi.org/10.1016/j.apcatb.2010.06.002.

[19] Z. Ilham, S. Saka, Reactivity of triglycerides and fatty acids in sub/super-critical dialkyl carbonates for biodiesel production, Zero-Carbon. Energy. Kyoto. (2012) 97–104, https://doi.org/10.1007/978-4-431-54067-0_10.

[20] X. Zhang, R. Tu, Z. Lu, J. Peng, C. Hou, Z. Wang, Hierarchical mesoporous metal–organic frameworks encapsulated enzymes: progress and perspective, Coord. Chem. Rev. 443 (2021) 214032, https://doi.org/10.1016/j.ccr.2021.214032.

[21] D.P. Wang, B.L. Yang, X.W. Zhai, L.G. Zhou, Synthesis of diethyl carbonate by catalytic alcoholysis of urea, Fuel Process. Technol. 88 (2007) 807–812, https://doi.org/10.1016/j.fuproc.2007.04.003.

[22] T.J. Bruno, A. Wolk, A. Naydich, Composition-explicit distillation curves for mixtures of diesel fuel with dimethyl carbonate and diethyl carbonate, Energy Fuel 23 (2009) 3989–3997, https://doi.org/10.1021/ef900153a.

[23] V. Rathore, S. Tyagi, B.L. Newalkar, R.P. Badoni, Glycerin free synthesis of Jatropha and Pongamia biodiesel in supercritical dimethyl and diethyl carbonate, Ind. Eng. Chem. Res. 53 (2014) 10525–10533, https://doi.org/10.1021/ie5011614.

[24] D. Fabbri, V. Bevoni, M. Notari, F. Rivetti, Properties of a potential biofuels obtained from soybean oil by transmethylation with dimethyl carbonate, Fuel 86 (2007) 690–697, https://doi.org/10.1016/j.fuel.2006.09.003.

[25] G.H. Zaid, E.A. Wolf, Synthesis of dialkyl carbonates, US patent 6452036, 2002.

[26] S.E. Onoji, S.E. Iyuke, A.I. Igbafe, D.B. Nkazi, Rubber seed oil: a potential renewable source of biodiesel for sustainable development in sub-Saharan Africa, Energy Convers. Manage. 110 (2016) 125–134, https://doi.org/10.1016/j.enconman.2015.12.002.

[27] Y.C. Dennis, X.W. Leung, M.K.H. Leung, A review on biodiesel production using catalyzed transesterification, Appl. Energy 87 (2010) 1083–1095, https://doi.org/10.1016/j.apenergy.2009.10.006.

[28] H. Imahara, E. Minami, S. Hari, S. Saka, Thermal stability of biodiesel in supercritical methanol, Fuel 87 (2008) 1–6, https://doi.org/10.1016/j.fuel.2007.04.003.

[29] S. Saka, D. Kusdiana, Kinetics of transesterification in rapeseed oil to biodiesel fuel as treated in supercritical methanol, Fuel 80 (2001) 693–698, https://doi.org/10.1016/S0016-2361(00)00140-X.

[30] M.N. Varma, P.A. Deshpande, G. Madras, Synthesis of biodiesel in super-critical alcohols and supercritical carbon dioxide, Fuel 89 (2010) 1641–1646, https://doi.org/10.1016/j.fuel.2009.08.012.

[31] M. Takase, Z. Ting, Z. Min, C. Yao, L. Hongyang, Y. Liuqing, W. Xiangyang, An expatriate review of neem, jatropha, rubber and karanja as multipurpose non-edible biodiesel resources and comparison of their fuel, engine and emission properties, Renew. Sustain. Energy Rev. 43 (2015) 495–520, https://doi.org/10.1016/j.rser.2014.11.019.

[32] S. Thapa, N. Indrawan, P.R. Bhoi, An overview on fuel properties and prospects of Jatropha biodiesel as fuel for engines, Environ. Technol. Inno. 9 (2018) 210–219, https://doi.org/10.1016/j.eti.2017.12.003.

[33] X.Z. Liang, J.G. Yang, Synthesis of a novel multi-SO₃H functionalized ionic liquid and its catalytic activities for biodiesel synthesis, Green Chem. 12 (2010) 201–204, https://doi.org/10.1039/B922960N.

[34] D. Qiqi, Y. Zifei, L. Jin, C. Yang, T. Hongbiao, W. Xiaocui, Zirconium-based MOFs-loaded ionic liquid-catalyzed preparation of biodiesel from Jatropha oil, Renew. Energy 163 (2021) 1588–1596, https://doi.org/10.1016/j.renene.2020.09.122.

[35] T. Heinze, K. Schwikal, S. Barthel, Ionic liquids as reaction medium in cellulose functionalization, Macromol. Technol. 5 (2005) 520–525, https://doi.org/10.1002/mabi.200400083.

[36] S. Bose, D.W. Armstrong, J.W. Petrich, Enzyme-catalyzed hydrolysis of cellulose in ionic liquids: a Green approach toward the production of biofuels, J. Phys. Chem. B 114 (2010) 8221–8227, https://doi.org/10.1021/jp9120518.

[37] I. Noshadi, B. Kanjilal, S. Du, G.M. Bollas, S.L. Suib, A. Provatas, F. Liu, R.S. Parnas, Catalyzed production of biodiesel and bio-chemicals from brown grease using ionic Liquid functionalized ordered mesoporous polymer, Appl. Energy 129 (2014) 112–122, https://doi.org/10.1016/j.apenergy.2014.04.090.

[38] M.A.A. Rani, A. Brant, L. Crowhurst, A. Dolan, M. Lui, N.H. Hassan, J.P. Hallett, P.A. Hunt, H. Niedermeyer, J.M. Perez-arlandis, Understanding the polarity of ionic liquids, Phys. Chem. Chem. Phys. 13 (2011) 16831–16840, https://doi.org/10.1039/c1cp21262a.

[39] T. Kai, G.L. Mak, S. Wada, T. Nakazato, H. Takanashi, Y. Uemura, Production of biodiesel fuel from canola oil with dimethyl carbonate using an active sodium methoxide catalyst prepared by crystallization, Bioresour. Technol. 163 (2014) 360–363, https://doi.org/10.1016/j.biortech.2014.04.030.

[40] N.B.A. DaSilveira, M.B. Alves, A.A.M. Lapis, J.M. Nachtigall, M.N. Eberlin, J. Dupont, P.A.Z. Suarez, 1-n-Butyl-3-methylimidazolium tetrachloro-indate (BMI.InCl4) as a media for the synthesis of biodiesel from vegetable oils, J. Catal. 249 (2007) 154–161, https://doi.org/10.1016/j.jcat.2007.04.015.

[41] A.A.M. Lapis, L.F. de Oliveira, B.A.D. Neto, J. Dupont, Ionic liquid supported acid/base-catalyzed production of biodiesel, ChemSusChem. 1 (2008) 759–762, https://doi.org/10.1002/cssc.200800077.

[42] F. Liu, S. Zuo, S. Kong, C. Qi, High-temperature synthesis of strong acidic ionic liquids functionalized, ordered and stable mesoporous polymers with excellent catalytic activities, Green Chem. 14 (2012) 1342–1349, https://doi.org/10.1039/C2GC16481C.

[43] Y. Jeon, W.S. Chi, J. Hwang, D.H. Kim, J.H. Kim, Y.-G. Shul, Core-shell nano-structured heteropoly acid-functionalized metal-organic frameworks: bifunctional heterogeneous catalyst for efficient biodiesel production, Appl. Catal. B Environ. 242 (2019) 51–59, https://doi.org/10.1016/j.apcatb.2018.09.071.

[44] A. Palani, N. Gokulakrishnan, M. Palanichamy, A. Pandurangan, Trans-esterification of dimethyl carbonate with diethyl carbonate over Al-Zn-MCM-41 and Al-MCM-41 molecular sieves, Appl. Catal. A Gen. 304 (2006) 152–158, https://doi.org/10.1016/j.apcata.2006.02.036.

[45] Y.F. He, X.X. Han, Q. Chen, L.X. Zhou, Transesterification of soybean oil to biodiesel by Brønsted-type ionic liquid acid catalysts, Chem. Eng. Technol. 36 (2013) 1559–1567, https://doi.org/10.1002/ceat.201300060.

[46] L.Q. He, S.J. Qin, T. Chang, Y.Z. Sun, X.R. Gao, Biodiesel synthesis from the esterification of free fatty acids and alcohol catalyzed by long-chain Brønsted acid ionic liquid, Catal. Sci. Technol. 3 (2013) 1102–1107, https://doi.org/10.1039/C2CY20714A.

[47] S. Liu, Z. Wang, S. Yu, C. Xie, Transesterification of waste oil to biodiesel using Bronsted acid ionic liquid as catalyst, Bull. Chem. Soc. Ethiop. 27 (2013) 289–294, https://doi.org/10.4314/bcse.v27i2.11.

[48] Z. Man, Y.A. Elsheikh, M.A. Bustam, S. Yusup, M.I.A. Mutalib, N.A. Muhammad, Brønsted ammonium ionic liquid-KOH two-stage catalyst for biodiesel synthesis from crude palm oil, Ind. Crop. Prod. 41 (2013) 144–149, https://doi.org/10.1016/j.indcrop.2012.04.032.

[49] P. Tundo, M. Selva, The chemistry of dimethyl carbonate, Acc. Chem. Res. 35 (2002) 706–716, https://doi.org/10.1016/S0920-5861(98)00440-7.

[50] P. Chitra, P. Venkatachalam, A. Sampathrajan, Optimisation of experimental procedure for biodiesel production from alkaline-catalysed transesterification of Jatropha curcas oil, Energy Sustain. Dev. 9 (2005) 13–18, https://doi.org/10.1016/S0973-0826(08)60518-9.

[51] Z.Y. Tang, L.Y. Wang, J.C. Yang, Transesterification of the crude Jatropha curcas L.oil catalyzed by micro-NaOH in supercritical and subcritical methanol, Eur. J. Lipid Sci. Technol. 109 (2007) 585–590, https://doi.org/10.1002/ejlt.200600254.

[52] N.C.O. Tapanes, D.A.G. Aranda, J.W.M. Carneiro, O.A.C. Antunes, Trans-esterification of Jatropha curcas oil glycerides: theoretical and experimental studies of biodiesel reaction, Fuel 87 (2008) 2286–2295, https://doi.org/10.1016/j.fuel.2007.12.006.

[53] H.J. Berchmans, K. Morishita, T. Takarada, Kinetic study of hydroxide-catalyzed methanolysis of Jatropha curcas-waste food oil mixture for biodiesel production, Fuel 104 (2013) 46–52, https://doi.org/10.1016/j.fuel.2010.01.017.

[54] H. Xing, T. Wang, Z. Zhou, Y. Dai, A review on Brønsted acid ionic liquids catalysts for biodiesel synthesis through transesterification, J. Mol. Catal. A Chem. 264 (2007) 53–59, https://doi.org/10.1016/j.molcata.2006.08.080.

[55] L. Andreani, J.D. Rocha, Use of ionic liquids in biodiesel production: a review, Braz. J. Chem. Eng. 29 (1) (2012) 1–13, https://doi.org/10.1590/S0104-66322012000100001.

[56] Y. Syamsuddin, M.N. Murat, B.H. Hameed, Transesterification of Jatropha oil with dimethyl carbonate to produce fatty acid methyl ester over reusable Ca–La–Al mixed-oxide catalyst, Energy Convers. Manage. 106 (2015) 1356–1361, https://doi.org/10.1016/j.enconman.2015.10.057.

[57] J. Lee, J.-M. Jung, J.-J. Oh, O. Yong Sik, E.K. Eilhann, Establishing a green platform for biodiesel synthesis via strategic utilization of biochar and dimethyl carbonate, Bioresour. Technol. 241 (2017) 1178–1181, https://doi.org/10.1016/j.biortech.2017.05.182.

[58] X. Li, X.-Y. He, Z.-L. Li, Y.-D. Wang, C.-Y. Wang, H. Shi, F. Wang, Enzymatic production of biodiesel from Pistacia chinensis bge seed oil using immobilized lipase, Fuel 92 (2012) 89–93, https://doi.org/10.1016/j.fuel.2011.06.048.

[59] J.M. Bernal, P. Lozano, E. Garcia-Verdugo, M.I. Burguete, G. Sanchez-Gomez, G. Lopez-Lopez, M.V. Pucheault, S.V. Luis, Supercritical synthesis of biodiesel, Molecules 17 (2012) 8696–8719, https://doi.org/10.3390/molecules17088696.

[60] P. Lozano, J.M. Bernal, S. Nieto, C. Gomez, E. Garcia-Verdugo, S.V. Luis, Active biopolymers in green non-conventional media: a sustainable tool for developing clean chemical processes, Chem. Commun. 51 (2015) 17361–17374, https://doi.org/10.1039/c5cc05408g.

[61] M. Lotti, J. Pleiss, F. Valero, P. Ferrer, Effects of methanol on lipases: molecular, kinetic and process issues in the production of biodiesel, Biotechnol. J. 10 (2015) 22–30, https://doi.org/10.1002/biot.201400158.

[62] L. Tasheer, B. Changmai, R. Gupta, D. Shi, K.J. Jenkinson, A.E.H. Wheatley, L. Rokhum, A mesoporous polysulfonic acid-formaldehyde polymeric catalyst for biodiesel production from Jatropha curcas oil, Renew. Energy 173 (2021) 415–421, https://doi.org/10.1016/j.renene.2021.04.004.

[63] P. Lozano, C. Gomez, S. Nieto, S.-G. Gregorio, G.-V. Eduardo, S.V. Luis, Highly selective biocatalytic synthesis of monoacylglycerides in sponge-like ionic liquids, Green Chem. 19 (2) (2017) 390–396, https://doi.org/10.1039/C6GC01969B.

[64] P.B. Subhedar, P.R. Gogate, Ultrasound assisted intensification of biodiesel production using enzymatic interesterification, Ultrason. Sonochem. 29 (2015) 67–75, https://doi.org/10.1016/j.ultsonch.2015.09.006.

[65] P. Chand, V.R. Chintareddy, J.G. Verkade, D. Grewell, Enhancing biodiesel production from soybean oil using ultrasonics, Energy Fuel. 24 (2010) https://doi.org/10.1021/ef9011752, 2010–2015.

[66] J.K. Raman, A. Sariah, P. Denis, E.S. Chan, R. Pogaku, Production of biodiesel using immobilized lipase—a critical review, Crit. Rev. Biotechnol. 28 (2008) 253–264, https://doi.org/10.1080/07388550802428392.

[67] A. Zulfiqar, M.W. Mumtaz, H. Mukhtar, J. Najeeb, A. Irfan, S. Akram, T. Touqeer, G. Nabi, Lipase-PDA-TiO2 NPs: an emphatic nano-biocatalyst for optimized biodiesel production from Jatropha curcas oil, Renew. Energy 169 (2021) 1026–1037, https://doi.org/10.1016/j.renene.2020.12.135.

[68] T. De Diego, P. Lozano, S. Gmouh, M. Vaultier, J.L. Iborra, Understanding structure–stability relationship of Candida Antarctica lipase B in ionic liquids, Biomacromolecules 6 (2005) 1457–1464, https://doi.org/10.1021/bm049259q.

[69] M.M. Soumanou, U.T. Bornscheuer, Improvement in lipase-catalyzed synthesis of fatty acid methyl esters from sunflower oil, Enzyme Microb. Technol. 33 (1) (2003) 97–103, https://doi.org/10.1016/S0141-0229(03)00090-5.

[70] M. Gamba, A.A.M. Lapis, J. Dupont, Supported ionic liquid enzymatic catalysis for the production of biodiesel, Adv. Synth. Catal. 350 (2008) 160–164, https://doi.org/10.1002/adsc.200700303.

[71] S.V. Ranganathan, S.L. Narasimhan, K. Mythukumar, An overview of enzymatic production of biodiesel, Bioresour. Technol. 99 (2008) 3975–3981, https://doi.org/10.1016/j.biortech.2007.04.060.

[72] A.D. Folasegun, O.A. Olubunmi, X. Jiayu, Z. Suojiang, Dimethyl carbonate mediated production of biodiesel at different reaction temperatures, Renew. Energy 68 (2014) 581–587, https://doi.org/10.1016/j.renene.2014.02.036.

[73] M.S. Khayoon, B.H. Hameed, Mg₁₊ₓCa₁₋ₓO₂ as reusable and efficientheterogeneous catalyst for the synthesis of glycerol carbonate via the transesterification of glycerol with dimethyl carbonate, Appl. Catal. A Gen. 466 (2013) 272–281, https://doi.org/10.1016/j.apcata.2013.06.044.

[74] M.M. Du, Q.X. Li, W.T. Dong, T. Geng, Y.J. Jiang, Synthesis of glycerol carbonate fromglycerol and dimethyl carbonate catalyzed by K₂CO₃/MgO, Res. Chem. Intermed. 38 (2012) 1069–1077, https://doi.org/10.1007/s11164-011-0443-3.

[75] J. Dupont, From molten salts to ionic liquids: a "nano" journey, Acc. Chem. Res. 44 (2011) 1223–1231, https://doi.org/10.1021/ar2000937.

[76] M. Tudorache, L. Protesescu, A. Negoi, V.I. Parvulescu, Recyclable biocatalytic composites of lipase-linked magnetic macro-/nano-particles for glycerol carbonate synthesis, Appl. Catal. A Gen. 437–438 (2012) 90–95, https://doi.org/10.1016/j.apcata.2012.06.016.

[77] K.A. Cushing, S.W. Peretti, Enzymatic processing of renewable glycerol intovalue-added glycerol carbonate, RSC Adv. 3 (2013) 18596–18604, https://doi.org/10.1039/c3ra43611b.

[78] K. Lanjekar, V.K. Rathod, Utilization of glycerol for the production of glycerolcarbonate through greener route, J. Environ. Chem. Eng. 1 (2013) 1231–1236, https://doi.org/10.1016/j.jece.2013.09.015.

[79] J.R. Ochoa-Gomez, O. Go mez-Jimenez-Aberasturi, B. Maestro-Madurga, A. Pesquera-Rodriguez, C. Ramirez-Lopez, L. Lorenzo-Ibarreta, J. Torrecilla-Soria, C. Maria, Villaran-Velasco, Synthesis of glycerol carbonate from glycerol and dimethyl carbonate by transesterification: catalyst screening and reaction optimization, Appl. Catal. A Gen. 366 (2009) 315–324, https://doi.org/10.1016/j.apcata.2009.07.020.

[80] A. Kumar, K. Iwatani, S. Nishimura, A. Takagaki, K. Ebitani, Promotion effect ofcoexistent hydromagnesite in a highly active solid base hydrotalcite catalyst for transesterifications of glycols into cyclic carbonates, Catal. Today 185 (2012) 241–246, https://doi.org/10.1016/j.cattod.2011.08.016.

[81] S. Pan, L. Zheng, R. Nie, S. Xia, P. Chen, Z. Hou, Transesterification of glycerolwith dimethyl carbonate to glycerol carbonate over Na-based zeolites, Chin. J. Catal. 33 (2012) 1772–1777, https://doi.org/10.1016/S1872-2067(11)60450-1.

[82] P. Fan, S. Xing, J. Wang, J. Fu, L. Yang, G. Yang, Sulfonated imidazolium ionic liquid-catalyzed transesterification for biodiesel synthesis, Fuel 188 (2017) 483–488, https://doi.org/10.1016/j.fuel.2016.10.068.

[83] X.Z. Liang, G.Z. Gong, H.H. Wu, J.G. Yang, Highly efficient procedure for the synthesis of biodiesel from soybean oil using chloroaluminate ionic liquid as catalyst, Fuel 88 (2009) 613–616, https://doi.org/10.1016/j.fuel.2009.10.008.

[84] F.A. Lee, J.A. Bennett, J.C. Manayil, K. Wilson, Heterogeneous catalysis for sustainable biodiesel production via esterification and transesterification, Chem. Soc. Rev. 43 (2014) 7887–7916, https://doi.org/10.1039/C4CS00189C.

[85] P.U. Naik, L. Petitjean, K. Refes, M. Picquet, L. Plasseraud, Imidazolium-2-carboxylate as an efficient, expeditious and eco-friendly organocatalyst for glycerol carbonate synthesis, Adv. Synth. Catal. 351 (2009) 1753–1756, https://doi.org/10.1002/adsc.200900280.

[86] H. Mutlu, J. Ruiz, S.C. Solleder, M.A.R. Meier, TBD catalysis with dimethyl carbonate: a fruitful and sustainable alliance, Green Chem. 14 (2012) 1728–1735, https://doi.org/10.1039/C2GC35191A.

[87] X.H. Song, Y. Wu, F.F. Cai, D.H. Pan, G.M. Xiao, High-efficiency and low-cost Li/ZnOcatalysts for synthesis of glycerol carbonate from glycerol transesterification: the role of Li and ZnO interaction, Appl. Catal. A Gen. 532 (2017) 77–85, https://doi.org/10.1016/j.apcata.2016.12.019.

[88] K.K. Hua, H.J. Wang, Y.H. Liu, C. Yang, KNO₃/CaO as cost-effective heterogeneouscatalyst for the synthesis of glycerol carbonate from glycerol and dimethyl carbonate, J. Ind. Eng. Chem. 28 (2015) 334–343, https://doi.org/10.1016/j.jiec.2015.03.012.

[89] R.X. Bai, S. Wang, F.M. Mei, T. Li, G.X. Li, Synthesis of glycerol carbonate from glycerol and dimethyl carbonate catalyzed by KF modified hydroxyapatite, J. Ind. Eng. Chem. 17 (2011) 777–781, https://doi.org/10.1016/j.jiec.2011.05.027.

[90] Z.M. Liu, J. Wang, M.Q. Kang, N. Yin, X.H. Wang, Y.S. Tan, Y.L. Zhu, Structure-activity correlations of LiNO₃/Mg₄AlO₅.₅ catalysts for glycerol carbonate synthesis fromglycerol and dimethyl carbonate, J. Ind. Eng. Chem. 21 (2015) 394–399, https://doi.org/10.1016/j.jiec.2014.09.031.

[91] Y.S. Lu, Z.W. Zhang, Y.F. Xu, G.R. Qian, CaFeAl mixed oxide derived heterogeneous catalysts for transesterification of soybean oil to biodiesel, Bioresour. Technol. 190 (2015) 438–441, https://doi.org/10.1016/j.biortech.2015.02.046.

[92] T.W. Turney, A. Patti, W. Gates, U. Shaheen, S. Kulasegaram, Formation of glycerol carbonate from glycerol and urea catalysed by metal monoglycer-olates, Green Chem. 15 (2013) 1925–1931, https://doi.org/10.1039/C3GC37028C.

[93] P. Kumar, P. With, V.C. Srivastava, R. Glaser, I.M. Mishra, Glycerol carbonate synthesis by hierarchically structured catalysts: catalytic activity and characterization, Ind. Eng. Chem. Res. 54 (2015) 12543–12552, https://doi.org/10.1021/acs.iecr.5b03846.

[94] A.C. Kerri, W.P. Steven, Enzymatic processing of renewable glycerol into valueadded glycerol carbonate, RSC Adv. 3 (2013) 18596–18604, https://doi.org/10.1039/C3RA43611B.

[95] K.H. Lee, C.H. Park, E.Y. Lee, Biosynthesis of glycerol carbonate from glycerol bylipase in dimethyl carbonate as the solvent, Bioproc. Biosyst. Eng. 33 (2010) 1059–1065, https://doi.org/10.1007/s00449-010-0431-9.

[96] V. Kumar, K. Vellingiri, D. Kukkar, S. Kumar, K.H. Kim, Recent advances and opportunities in the treatment of hydrocarbons and oils: metal-organic frameworks-based approaches, Crit. Rev. Environ. Sci. Technol. 49 (7) (2019) 587–654, https://doi.org/10.1080/10643389.2018.1553402.

[97] V. Rathore, G. Madras, Synthesis of biodiesel from edible and non-edible oils in supercritical alcohols and enzymatic synthesis in supercritical carbon dioxide, Fuel 86 (2007) 2650–2659, https://doi.org/10.1016/j.fuel.2007.02.014.

[98] H. Pan, H. Li, H. Zhang, A. Wang, D. Jin, S. Yang, Effective production of biodiesel from non-edible oil using facile synthesis of imidazolium salts-based Brønsted-Lewis solid acid and co-solvent, Energy Convers. Manage. 166 (2018) 534–544, https://doi.org/10.1016/j.enconman.2018.04.061.

[99] A.D. Crescenzo, M. Aschi, E.D. Canto, S. Giordani, D. Demurtas, A. Fontana, Structural modifications of ionic liquidsurfactants for improving the water dispersibility of carbon nanotubes: an experimental and theoretical study, Phys. Chem. Chem. Phys. 13 (23) (2011) 11373–11383, https://doi.org/10.1039/c1cp20140a.

[100] B.M. Panchal, M.V. Padul, M.S. Kachole, Optimization of biodiesel from dried biomass of Schizochytrium limacinum using methanesulfonic acid-DMC, Renew. Energy 86 (2016) 1069–1074, https://doi.org/10.1016/j.renene.2015.09.027.

[101] M.R. Islam, Y.M. Kurle, J.L. Gossage, T.J. Benson, Kinetics of triazabicyclodecene-catalyzed canola oil conversion to glycerol-free biofuel using dimethyl carbonate, Energy Fuel 27 (2013) 1564–1569, https://doi.org/10.1021/ef4003018v.

[102] C. Alessio, J.S. Ribeiro, D. Celante, L. Brondani, F. Castilhos, Kinetics of methylesters production with dimethyl carbonate over niobium phosphate, Energy Convers. Manage. 151 (2017) 670–680, https://doi.org/10.1016/j.enconman.2017.09.010.

[103] M. Rathnam, G. Madras, Conversion of Schizochitrium limacinum microalgae to biodiesel by noncatalytic transesterification using various supercritical fluids, Bioresour. Technol. 288 (2019) 121538, https://doi.org/10.1016/j.biortech.2019.121538.

[104] S. Sun, L. Zhang, X. Meng, Z. Xin, Kinetic study on lipase catalyzed transesterification of palm oil and dimethyl carbonate for biodiesel production, J. Renew. Sustain. Energy 5 (2013), 033127, https://doi.org/10.1063/1.4807744.

[105] D.C. Panadare, V.K. Rathod, Microwave assisted enzymatic synthesis of biodiesel with waste cooking oil and dimethyl carbonate, J. Mol. Catal. B Enzym. 133 (2016) S18–S24, https://doi.org/10.1016/j.molcatb.2017.01.002.

[106] B. Rejasse, S. Lamare, M.D. Legoy, T. Besson, Influence of microwave irradiation onenzymatic properties: applications in enzyme chemistry, J. Enzyme Inhib. Med. Chem. 22 (2007) 519–527, https://doi.org/10.1080/14756360701204996.

[107] J. Esteban, E. Dominguez, M. Ladero, G.-O. Felix, Kinetics of the production of glycerol carbonate by transesterification of glycerol with dimethyl and ethylene carbonate using potassium methoxide, a highly active catalyst, Fuel Process. Technol. 138 (2015) 243–251, https://doi.org/10.1016/j.fuproc.2015.06.012.

[108] D.Y.C. Leung, X. Wu, M.K.H. Leung, A review on biodiesel production using catalyzed transesterification, Appl. Energy 87 (2010) 1083–1095, https://doi.org/10.1016/j.apenergy.2009.10.006.

[109] V.G. Deshmane, Y.G. Adewuyi, Synthesis and kinetics of biodiesel formation via calcium methoxide base catalyzed transesterification reaction in the absence and presence of ultrasound, Fuel 107 (2013) 474–482, https://doi.org/10.1016/j.fuel.2012.12.080.

[110] A. Birla, B. Singh, S.N. Upadhyay, Y.C. Sharma, Kinetics studies of synthesis of biodiesel from waste frying oil using a heterogeneous catalyst derived from snail shell, Bioresour. Technol. 106 (2012) 95–100, https://doi.org/10.1016/j.biortech.2011.11.065.

[111] M. Berrios, J. Angel, S. Lopez, Kinetic study of the esterification of free fatty acids(FFA) in sunflower oil in sunflower oil, Fuel 86 (2007) 2383–2388, https://doi.org/10.1016/j.fuel.2007.02.002.

[112] J. Li, X. Peng, M. Luo, C.-J. Zhao, C.-B. Gu, Y.-G. Zu, Y.-J. Fu, Biodiesel production from Camptotheca acuminata seed oil catalyzed by novel Bronsted–Lewis acidic ionic liquid, Appl. Energy 115 (2014) 438–444, https://doi.org/10.1016/j.apenergy.2013.10.025.

[113] X.H. Qi, M. Watanabe, T.M. Aida, R.L. Smith Jr., Efficient process for conversion of fructose to 5-hydroxymethylfurfural with ionic liquids, Green Chem. 11 (2009) 1327–1331, https://doi.org/10.1039/B905975J.

[114] M. Ghiaci, B. Aghabarari, S. Habibollahi, A. Gil, Highly efficient Bronstedacidic ionic liquid-based catalysts for biodiesel synthesis from vegetable oils, Bioresour. Technol. 102 (2010) 1200–1204, https://doi.org/10.1016/j.biortech.2010.09.095.

[115] H. Pan, H. Li, H. Zhang, A.P. Wang, S. Yang, Acidic ionic liquid-functionalized mesoporous melamine-formaldehyde polymer as heterogeneous catalyst for biodiesel production, Fuel 239 (2019) 886–895, https://doi.org/10.1016/j.fuel.2018.11.093.

[116] F. Guo, Z. Fang, X.F. Tian, Y.D. Long, L.Q. Jiang, One-step production of biodiesel from Jatropha oil with high-acid value in ionic liquids, Bioresour. Technol. 140 (2013) 447–450, https://doi.org/10.1016/j.biortech.2013.03.095.

[117] W.K. Teng, G.C. Ngoh, R. Yusoff, M.K. Aroua, A review on the performance of glycerol carbonate production via catalytic transesterification: effects of influencing parameters, Energy Convers. Manage. 88 (2014) 484–497, https://doi.org/10.1016/j.enconman.2014.08.036.

[118] M. Wang, K.L. Nie, F. Yun, H. Cao, L. Deng, F. Wang, T.W. Tan, Biodiesel with low temperature properties: enzymatic synthesis of fusel alcohol fatty acidester in a solvent free system, Renew. Energy 83 (2015) 1020–1025, https://doi.org/10.1016/j.renene.2015.05.058.

[119] P. Verma, M.P. Sharma, G. Dwivedi, Impact of alcohol on biodiesel production and properties, Renew. Sustain. Energy Rev. 56 (2016) 319–333, https://doi.org/10.1016/j.rser.2015.11.048.

[120] N.N.A.N. Yusuf, S.K. Kamarudin, Z. Yaakub, Overview on the current trends in biodiesel production, Energy Convers. Manage. 52 (2011) 2741–2751, https://doi.org/10.1016/j.enconman.2010.12.004.

[121] B.K. Barnwal, M.P. Sharma, Prospects of biodiesel production from vegetable oils in India, Renew. Sustain. Energy Rev. 9 (2005) 363–378, https://doi.org/10.1016/j.rser.2004.05.007.

[122] R.E. Bailis, J. Baka, Greenhouse gas emissions and land use change from Jatropha curcas based jet fuel in Brazil, Environ. Sci. Technol. 44 (2010) 8684–8692, https://doi.org/10.1021/es1019178.

[123] B.M. Panchal, S.A. Deshmukh, M.R. Sharma, Production and kinetic transesterification of biodiesel from yellow grease with dimethyl carbonate using methanesulfonic acid as a catalyst, Environ. Prog. Sustain. Energy 36 (2017) 802–807, https://doi.org/10.1002/ep.12559.

[124] J.P. Szybist, J. Song, M. Alam, A.L. Boehman, Biodiesel combustion, emissions and emission control, Fuel Process. Technol. 88 (7) (2007) 679–691, https://doi.org/10.1016/j.fuproc.2006.12.008.

[125] B. Panchal, S.J. Qin, T. Chang, Y.Z. Sun, J.X. Wang, K. Bian, Production of methyl esters from fried soybean oil using dimethyl carbonate with hydrobromic acid, Energy Rep. 5 (2019) 1463–1469, https://doi.org/10.1016/j.egyr.2019.10.007.

[126] A.S. Silitonga, H.H. Masjuki, T.M.I. Mahlia, H.C. Ong, W.T. Chong, M.H. Boosroh, Overview properties of biodiesel diesel blends from edibleand non-edible feedstock, Renew. Sustain. Energy Rev. 22 (2013) 346–360, https://doi.org/10.1016/j.rser.2013.01.055.

[127] S.D. Sanford, J.M. White, P.S. Shah, C. Wee, M.A. Valverde, G.R. Meier, Feedstock and Biodiesel Characteristics Report, 2009, Renewable Energy Group, Ames, IA, USA, 2010.

[128] D.A. Wardle, Global sale of green air travel supported using biodiesel, Renew. Sustain. Energy Rev. 7 (2003) 1–64, https://doi.org/10.1016/S1364-0321(03)00002-9.

[129] J. Gardy, A. Osatiashtiani, O. Cespedes, A. Hassanpour, X. Lai, A.F. Lee, K. Wilson, M. Rehan, A magnetically separable $SO_4/Fe-Al-TiO_2$ solid acid catalyst for biodiesel production from waste cooking oil, Appl. Catal. B Environ. 234 (2018) 268–278, https://doi.org/10.1016/j.apcatb.2018.04.046.

[130] F.P. Byrne, S. Jin, G. Paggiola, T.H.M. Petchey, J.H. Clark, T.J. Farmer, A.J. Hunt, C. Robert McElroy, J. Sherwood, Tools and techniques for solvent selection: green solvent selection guides, Sustain. Chem. Process. 4 (2016) 7, https://doi.org/10.1186/s40508-016-0051-z.

[131] B. Panchal, T. Chang, S.J. Qin, Y.Z. Sun, J.X. Wang, K. Bian, Process optimization using novel acidic ionic liquids and the kineticsmodeling of methyl esters using Jatropha curcas oil with dimethyl carbonate, Fuel 258 (2019) 116165, https://doi.org/10.1016/j.fuel.2019.116165.

[132] P.B. Zhang, Y.L. Liu, M.M. Fan, P.P. Jiang, Catalytic performance of a novel amphiphilic alkaline ionic liquid for biodiesel production: influence of basicity and conductivity, Renew. Energy 86 (2016) 99–105, https://doi.org/10.1016/j.renene.2015.08.008.

[133] R. Alenezi, R.C.D. Santos, S. Raymahasay, G.A. Leeke, Improved biodiesel manufacture at low temperature and short reaction time, Renew. Energy 53 (2013) 242–248, https://doi.org/10.1016/j.renene.2012.11.019.

[134] M.F. Rabiah Nizah, Y.H. Taufiq-Yap, U. Rashid, S.T. Hwa, Z.A. Shajaratun Nur, A. Islam, Production of biodiesel from non-edible Jatropha curcas oil via transesterification using $Bi_2O_3-La_2O_3$ catalyst, Energy Convers. Manage. 88 (2014) 1257–1262, https://doi.org/10.1016/j.enconman.2014.02.072.

[135] J.R. Ochoa-Gomez, O. Gomez-Jimenez-Aberasturi, C. Ramirez-Lopez, B. MaestroMadurga, Synthesis of glycerol 1,2-carbonate by transesterification of glycerol with dimethyl carbonate using triethylamine as a facile separable homogeneous catalyst, Green Chem. 14 (2012) 3368–3376, https://doi.org/10.1039/C2GC35992H.

[136] J.R. Ochoa-Gomez, O. Gomez-Jimenez-Aberasturi, B. Maestro-Madurga, A. Pesquera-Rodriguez, C. Ramirez-Lopez, L. Lorenzo-Ibarreta, J. Torrecilla-Soria, M.C. Villaran-Velasco, Synthesis of glycerol carbonate from glycerol and dimethyl carbonate by transesterification: catalyst screening and reaction optimization, Appl. Catal. A Gen. 366 (2009) 315–324, https://doi.org/10.1016/j.apcata.2009.07.020.

[137] M.J. Climent, A. Corma, P.D. Frutos, S. Iborra, M. Noy, A. Velty, P. Concepcion, Chemicals from biomass: synthesis of glycerol carbonate by transesterification and carbonylation with urea with hydrotalcite catalysts, J. Catal. 269 (2010) 140–149, https://doi.org/10.1016/j.jcat.2009.11.001.

[138] Y.T. Algoufi, B.H. Hameed, Synthesis of glycerol carbonate by transesterification of glycerol with dimethyl carbonate over K-zeolite derived fromcoal fly ash, Fuel Process. Technol. 126 (2014) 5–11, https://doi.org/10.1016/j.fuproc.2014.04.004.

[139] G. Parameswaram, M. Srinivas, B. Hari Babu, P.S. Sai Prasad, N. Lingaiah, Transesterification of glycerol with dimethyl carbonate for the synthesis of glycerol carbonate over Mg/Zr/Sr mixed oxide base catalysts, Catal. Sci. Technol. 3 (2013) 3242–3249, https://doi.org/10.1039/c3cy00532a.

[140] Z.M. Liu, J.W. Wang, M.Q. Kang, N. Yin, X.K. Wang, Y.S. Tan, Y.L. Zhu, Structure-activity correlations of $LiNO_3/Mg_4AlO_{5.5}$ catalysts for glycerol carbonate synthesis from glycerol and dimethyl carbonate, J. Ind. Eng. Chem. 21 (2015) 394–399, https://doi.org/10.1016/j.jiec.2014.02.051.

[141] G. Rokicki, P. Rakoczy, P. Parzuchowski, M. Sobiecki, Hyperbranched aliphatic polyethers obtained from environmentally benign monomer: glycerol carbonate, Green Chem. 7 (2005) 529–539, https://doi.org/10.1039/b501597a.

[142] Y. Patel, J. George, S.M. Pillai, P. Munshi, Effect of liophilicity of catalyst in cycliccarbonate formation by transesterification of polyhydric alcohols, Green Chem. 11 (2009) 1056–1060, https://doi.org/10.1039/B903529J.

[143] C. Chiappe, S. Rajamani, Synthesis of glycerol carbonate from glycerol anddimethyl carbonate in basic ionic liquids, Pure Appl. Chem. 84 (2012) 755–762, https://doi.org/10.1351/PAC-CON-11-07-06.

[144] S.M. Gade, M.K. Munshi, B.M. Chherawalla, V.H. Rane, A.A. Kelkar, Synthesis ofglycidol from glycerol and dimethyl carbonate using ionic liquid as a catalyst, Catal. Commun. 27 (2012) 184–188, https://doi.org/10.1016/j.catcom.2012.07.003.

[145] M. Tudorache, A. Negoi, L. Protesescu, I.P. Vasile, Biocatalytic alternative for bio-glycerol conversion with alkyl carbonates via a lipase-linked magnetic nano-particles assisted process, Appl. Catal. B Environ. 145 (2014) 120–125, https://doi.org/10.1016/j.apcatb.2012.12.033.

[146] P.J. Seong, B.W. Jeon, M. Lee, D.H. Cho, D.K. Kim, K.S. Jung, S.W. Kim, S.O. Han, Y.H. Kim, C. Park, Enzymatic coproduction of biodiesel and glycerolcarbonate from soybean oil and dimethyl carbonate, Enzyme Microb. Technol. 48 (2011) 505–550, https://doi.org/10.1016/j.enzmictec.2011.02.009, 9.

[147] X.X. Wang, P. Zhang, P.L. Cui, W.G. Cheng, S.J. Zhang, Glycerol carbonate synthesis from glycerol and dimethyl carbonate using guanidine ionic liquids, Chin. Times. J. Chem. Eng. 25 (2017) 1182–1186, https://doi.org/10.1016/j.cjche.2017.06.025.

[148] L.P. Zhang, B.Y. Sheng, Z. Xin, Q. Liu, S.Z. Sun, Kinetics of transesterification of palm oil and dimethyl carbonate for biodiesel production at the catalysis of heterogeneous basecatalyst, Bioresour. Technol. 101 (2010) 8144–8150, https://doi.org/10.1016/j.biortech.2010.05.069.

[149] J.B. Li, T. Wang, Coupling reaction and azeotropic distillation for the synthesis ofglycerol carbonate from glycerol and dimethyl carbonate, Chem. Eng. Process 49 (2010) 530–535, https://doi.org/10.1016/j.cep.2010.04.003.

[150] B.M. Panchal, S.A. Deshmukh, D.S. Panchal, M.R. Sharma, Kinetics of the transesterification of non-edible Thevetia peruviana seed oil with dimethyl carbonatecatalyzed by potassium methoxide, Egypt. J. Petrol. 26 (2017) 363–370, https://doi.org/10.1016/j.ejpe.2016.05.012.

[151] T. Maneerung, S. Kawi, Y. Dai, C. Wang, Sustainable biodiesel production via transesterification of waste cooking oil by using CaO catalysts prepared from chicken manure, Energy Convers. Manage. 123 (2016) 487–497, https://doi.org/10.1016/j.enconman.2016.06.071.

[152] B.M. Panchal, T. Chang, S.J. Qin, Y.Z. Sun, J.X. Wang, K. Bian, Optimization and kinetics of tung nut oil transesterification with methanol using novel solid acidic ionic liquid polymer as catalyst for methyl ester synthesis, Renew. Energy 151 (2019) 796–804, https://doi.org/10.1016/j.renene.2019.11.066.

[153] B. Mahiran, A.K. Mohd, M. Rosfarizan, B.A. Arbakariya, Optimization and

kinetic study on the synthesis of palm oil ester using lipozyme TLIM, J. Mol. Catal. B Enzym. 85 (2013) 214–219, https://doi.org/10.1016/j.molcatb.2012.09.013.

[154] B.M. Panchal, S.B. Dhoot, S.A. Deshmukh, M.R. Sharma, M.S. Kachole, Production of DMC-BioD from Pongamia pinnata seed oil using dimethyl carbonate, Fuel 109 (2013) 201–205, https://doi.org/10.1016/j.fuel.2012.12.052.

[155] Y.Q. Ma, Q.H. Wang, L. Zheng, Z. Gao, Q. Wang, Y.H. Ma, Mixed methanol/ethanol on transesterification of waste cooking oil using Mg/Al hydrotalcite catalyst, Energy 107 (2016) 523–531, https://doi.org/10.1016/j.energy.2016.04.066.

[156] B.M. Panchal, H.M. Kalaji, Synthesis and use of a catalyst in the production of biodiesel from Pongamia Pinnata seed oil with dimethyl carbonate, Int. J. Green Energy 14 (2017) 624–631, https://doi.org/10.1080/15435075.2017.1313739.

[157] B. Jiang, Y.M. Wang, L.H. Zhang, Y.L. Sun, H.W. Yang, B.Y. Wang, N. Yang, Biodiesel production via transesterification of soybean oil catalyzed by superhydrophobic orous poly(ionic liquid) solid base, Energy Fuel. 31 (2017) 5203–5214, https://doi.org/10.1021/acs.energyfuels.7b00544.

[158] U.M. Zahoor, B. Azmi, M. Zakaria, K. Amir, M. Nawshad, S. Ariyanti, Preparation and kinetic study of biodiesel production from waste cooking oil using new functionallized ionic liquids as catalysts, Renew. Energy 114 (2017) 755–765, https://doi.org/10.1016/j.renene.2017.07.085.

[159] Z.I. Ishak, N.A. Sairi, Y. Alias, M. Kheireddine, T. Aroua, R. Yusoff, A review of ionic liquids as catalysts for transesterification reactions of biodiesel and glycerol carbonate production, Catal. Rev. (2017). https://doi.org/10.1080/01614940.2016.1268021.

PRINCIPAL
Late Ramesh Warpudkar Arts. & Com ·
College, Sonpeth Dist. Parbhani