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journal homepage: [www.elsevier.com/locate/jtice](http://www.elsevier.com/locate/jtice)Evaluating the optimum operating parameters of biodiesel production process from soybean oil using the  $\text{Li}_2\text{TiO}_3$  catalyst

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## ABSTRACT

This study focuses on the transesterification of soybean oil into biodiesel using  $\text{Li}_2\text{TiO}_3$ .  $\text{Li}_2\text{TiO}_3$  is prepared through a solid-state reaction that involves mixing and grinding  $\text{TiO}_2$  and  $\text{Li}_2\text{CO}_3$  followed by the calcination at 800 °C for 2 h. The prepared  $\text{Li}_2\text{TiO}_3$  is characterized by X-ray diffraction (XRD), Field Emission Scanning Electron Microscope (FE-SEM), and BET, and the Hammett indicator is applied to obtain their physical and chemical properties.  $\text{Li}_2\text{TiO}_3$  has never been studied as a solid catalyst for transesterification reaction. Under optimal reaction conditions, namely a methanol:oil molar ratio of 24:1, a catalyst amount of 6 wt%, and a reaction temperature of 65 °C for 2 h, a biodiesel conversion rate of 98.5% is obtained. Moreover, different vegetable oil and used cooking oil are used as the raw materials for the biodiesel production.  $\text{Li}_2\text{TiO}_3$  can be easily recovered and reused for ten cycles without significant deactivation.

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## 1. Introduction

The increasing pollution and the shortage of fuels have forced human beings to search for sustainable use of the remaining resources. Biodiesel has been alternatively used for preventing human and environment from the problems of consuming non-renewable energy sources as fossil fuels [1–3].

Heterogeneous solid catalysts have several advantages, such as easy separation of catalysts, recyclability, and eco-friendliness [4–7]. Hence, the purification and washing steps can be eliminated from the process. Furthermore, it is interesting to modify the structures of surface metal oxide species in order to improve their catalytic properties for specific applications. Among all alkali metals (Li, Na, K) with these modification properties, alkali metals contain the strong base sites, either as bulk or supported metal oxide ( $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ) [8,9], and the structure and the catalytic properties of the surface alkali metals species are strongly influenced by the metal oxide supports. However, this reaction is associated with several difficulties in using basic solid catalysts, from an industrial perspective, involving the surface active sites being easily decayed upon exposing the catalyst to air. Most of the basic solid catalysts need to be resolved the removal of water and carbon dioxide from the surfaces to enhance their catalytic activities [10]. In earlier studies [11–13], found that lithium silicate and  $\text{Li}_2\text{CO}_3$  catalytically

tolerated the exposure to air. Therefore, lithium silicate and  $\text{Li}_2\text{CO}_3$  had great potential for the use as a catalyst. Additionally, Li-based catalysts show a very high activity promoting transesterification reaction [14,15]. Dai et al. [14] reported that the  $\text{LiAlO}_2$  catalyst was prepared by solid-state reaction and enhanced the conversion. Chen et al. [15] reported that the significant enhancement of catalytic activity was achieved for  $\text{Li}_2\text{CO}_3$  with  $\text{SiO}_2$ , leading to a highest basicity. Modification of previously synthesized catalysts with  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  to improve the structure and catalytic properties was strongly influenced by the factors [16,17].

$\text{TiO}_2$  is well known to be a cheap, readily available and non-toxic oxide support in catalytic reactions.  $\text{TiO}_2$  is used in various catalytic applications due to the unique combination of properties, such as stability, relatively high surface area, sintering resistance, resistance to poisoning, and low cost which make it an attractive potential catalyst for many reactions [18]. It is obvious that the use of  $\text{TiO}_2$  can make the synthesized catalyst products much more cost-effective.  $\text{TiO}_2$  has the potential for commercializing a prepared catalyst because of its low cost, high yield, and easy control.

In this paper, the  $\text{Li}_2\text{TiO}_3$  catalyst is prepared and applied to biodiesel production through the transesterification of soybean oil. To the best of our knowledge, this is the first attempt to use  $\text{Li}_2\text{TiO}_3$  as a catalyst for biodiesel production. The process parameters with the most significance in affecting biodiesel production from catalyzed transesterification of soybean oil include calcination temperature, calcination time, methanol/oil molar ratio, catalyst amount and reusability. Moreover, the catalyst reuse in various

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oil transesterification reactions is evaluated in order to perform a biodiesel production.

## 2. Materials and methods

### 2.1. Catalyst preparation

Soybean oil (TTET Union Co., Taiwan), methanol (ACS grade, ECHO Chemical Co., Taiwan),  $\text{TiO}_2$  (Shimakyu's Pure Chemicals, Osaka, Japan),  $\text{CaO}$  (Shimakyu's Pure Chemicals, Osaka, Japan) and  $\text{Li}_2\text{CO}_3$  (Shimakyu's Pure Chemicals, Osaka, Japan) were used as received. The fatty acid composition in the soybean oil as follows: 11.2%, palmitic acid; 4.44%, stearic acid; 25.85%, oleic acid; 50.79%, linoleic acid; 6.06%, linolenic acid; and traces of other fatty acids.

The solid-state reaction was used for the preparation of  $\text{Li}_2\text{TiO}_3$  oxide nanocomposite.  $\text{TiO}_2$  powder was added to an aqueous solution containing  $\text{Li}_2\text{CO}_3$ . Finally, the mixture was thoroughly and the as-prepared solution was dried at 110 °C for 12 h, followed by calcinations in air at 700, 800, 900 and 1000 °C for 2 h.

### 2.2. Reaction procedures

The conversion of soybean oil to biodiesel was performed in a 250-ml flat-bottomed flask, equipped with a reflux condenser and a magnetic stirrer. The reactor was initially filled with 12.5 g of soybean oil, which was heated to 65 °C for 2 h while stirring at 300 rpm. The reactant was stirred evenly to avoid splashing in the flask at the stirring speed. The timing of the reaction was initiated as soon as the mixture of methanol and the catalyst was added into the reactor. The effects of molar ratio of methanol to oil (12:1–30:1), and catalyst/oil weight ratio (2–10 wt.%), on the conversion of triglycerides to biodiesel were investigated. All of the experiments were performed at atmospheric pressure. After the transesterification reaction, DI water was added into the reaction mixture to stop the reaction. The biodiesel and glycerol layers were easily separated due to differing densities, of 0.86 and 1.126 g/cm<sup>3</sup>, respectively. A supernatant was filtered through a common filter paper, and then excess methanol and water were evaporated prior to FAME analysis.

### 2.3. Catalyst characterization

The base strength of the samples ( $H_-$ ) was determined using Hammett indicators [19]. Approximately 50 mg of the sample was shaken with 1 ml methanol solution of the Hammett indicator. 2 h were allowed to elapse for the reaching of equilibrium after which no additional change of color took place. The basic strength was defined as being stronger than the weakest indicator which exhibited a color change, and weaker than the strongest indicator which produced no color change. Bromthymol blue ( $H_- = 7.2$ ), phenolphthalein ( $H_- = 9.8$ ), 2,4-dinitroaniline ( $H_- = 15.0$ ), and 4-nitroaniline ( $H_- = 18.4$ ), at a concentration of 0.02 mol/l were obtained from Sigma–Aldrich (St. Louis, MO, USA) and used as Hammett indicators. The precipitates were further characterized. An X-ray powder diffractometer (XRD) (MAC Science MXP18) was used to identify the crystalline species of catalysts. A Cu tube serving as the X-ray source was employed to estimate the active site phase, and the working voltage and current was 40 kV and 80 mA, respectively. The powdered samples were pressed onto suitable holders. The scanning range of  $2\theta$  was from 20° to 80°. Diffraction patterns were manually analyzed with the Joint Committee of Powder Diffraction Standard (JCPDS) card. Field emission scanning electron microscopy (FESEM; Model JSM-6700F, JEOL, Tokyo, Japan) operated at 5 kV accelerating voltage. FESEM was used to observe the morphologies of  $\text{Li}_2\text{TiO}_3$ . The samples were immobilized on the

copper holder with the carbon glue. Before analysis, the holder with samples was pretreated at 200 °C. The Brunauer–Emmett–Teller (BET) surface area of the  $\text{Li}_2\text{TiO}_3$  was measured at –196 °C by gravimetric methods with a BET-201-AEL apparatus. The BET surface area was calculated from the adsorption isotherm, and the ratio of pore volume and the average pore diameter was obtained from the pore size-volume distribution.

### 2.4. Analytical methods

The FAME concentration was calculated using the internal standard method (according to the EN 14,103 method). In this study, gas chromatograph (Thermo Trace GC Ultra, Thermo Co., Austin, Texas, USA.) equipped with a flame ionization detector and capillary column Tr-biodiesel (F), Thermo Co. (length 30 m, internal diameter 0.25 mm and film thickness 0.25 μm) using methyl heptadecanoate as an internal standard. Nitrogen was used as the carrier gas with a linear velocity of 2 ml/min. The oven temperature at 120 °C, held for 1 min, then the temperature program started at 120 °C with increase to 220 °C at a rate of 30 °C/min and an increase to 250 °C at a rate of 10 °C/min, reached 250 °C hold time of 2 min. The diluted solution with methyl heptadecanoate was added as an internal FAME standard. The most common peaks were observed at C16:0, C17:0, C18:0, C18:1, C18:2, and C18:3. The conversion was determined according to the following equation.

$$\text{Conversion \%} = \frac{\Sigma A - A_{EI}}{A_{EI}} \times \frac{C_{EI} \times A_{EI}}{m} \times 100\%$$

$\Sigma A$ : sum of areas of all peaks ranging from C14:0 to C24:0,  $A_{EI}$ : heptadecanoic acid methyl ester IS area,  $C_{EI}$ : concentration (mg/ml) of heptadecanoic acid methyl ester solution,  $V_{EI}$ : volume of heptadecanoic acid methyl ester solution added to sample,  $m$ : mass of the sample (mg).

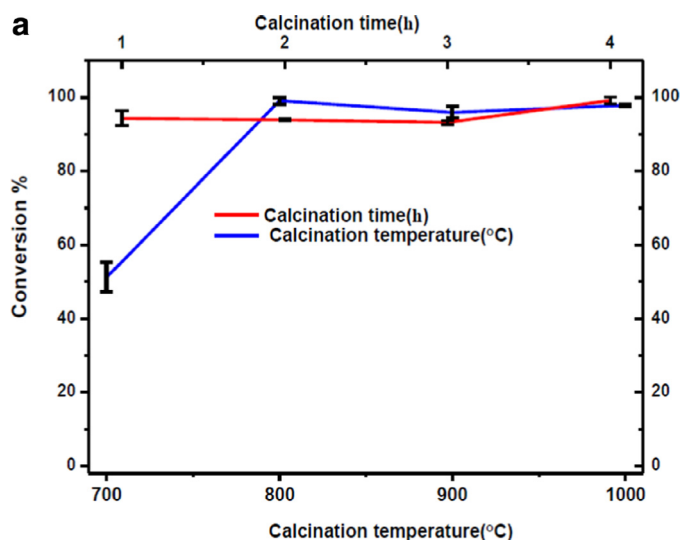
In order to quantitatively evaluate leaching of the solid base catalyst under the reaction conditions, some parts of the samples taken from the reactor were carefully filtered, and the residual methanol was evaporated in a rotary evaporator so that the FAME and glycerol were left as a separate phase. After the evaporation, the dry fraction was treated with 0.1 mol/l hydrochloric acid. The resulting solution was analyzed by inductively coupled plasma optical emission spectroscopy (ICP-OES, Spectro Genesis) to determine the Li concentration.

## 3. Results and discussion

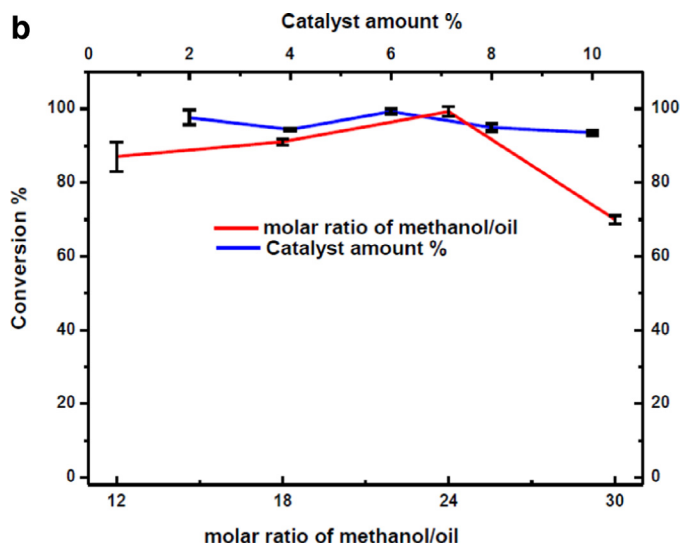
### 3.1. Reaction studies

Fig. 1 shows different calcination temperatures of  $\text{Li}_2\text{TiO}_3$  through the transesterification process. With the calcination temperature at 700 °C, the conversion achieves 51.3%, and the higher conversion 98.5% appears on the calcination temperature at 800 °C. However, the transfer rate decreases at the calcination temperature 1000 °C. As can be seen, a calcination temperature of 700 °C is not sufficient to produce highly active  $\text{Li}_2\text{TiO}_3$  for transesterification and, according to the XRD analysis, the deactivation of the catalyst after its calcination at high temperature is probably the result of the loss of active sites, by the sublimation and agglomeration into the structure. Therefore, the optimal calcination temperature is 800 °C in this study. Fig. 1 shows the transfer rate increases with calcination time and has a maximum value at 4 h at 800 °C. The result suggests that the main crystalline structure of the samples corresponding to  $\text{TiO}_2$  is transformed to the  $\text{Li}_2\text{TiO}_3$  phase after the solid-state synthesis with  $\text{Li}_2\text{CO}_3$  is finished during 4 hrs at 800 °C.

The stoichiometric molar ratio of methanol to oil required for transesterification is 3:1 [20]. As shown in Fig. 2, the conversion



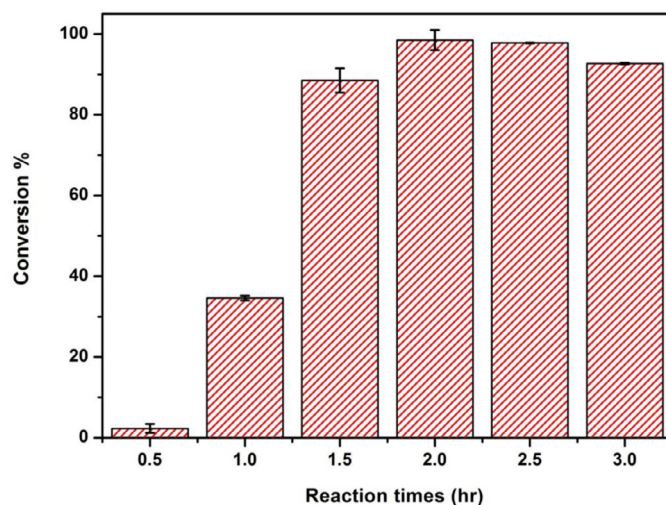
**Fig. 1.** Influence of calcination temperature and calcination time on the conversion reaction. (b) Influence of the methanol/oil molar ratio and catalyst amount on the conversion rate (reaction conditions: soybean oil; 12.5 g, reaction temperature; 65 °C, and reaction time; 2 h).



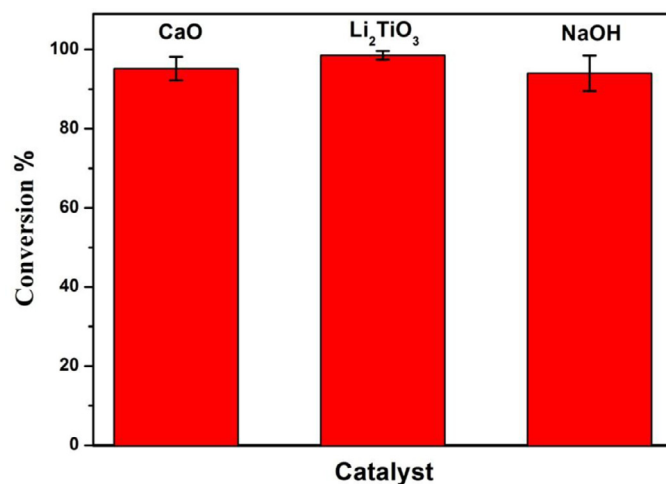
**Fig. 2.** Influence of the methanol/oil molar ratio and catalyst amount on the conversion rate (reaction conditions: soybean oil; 12.5 g, reaction temperature; 65 °C, and reaction time; 2 h).

increases considerably as the methanol-loading amount increases. The maximal conversion ratio is 98.5% at the methanol/oil molar ratio of 24:1. The increase in conversion is due to the shift in equilibrium toward the formation of FAME. Further increasing the methanol to oil ratio causes a decrease in the oil concentration and accordingly decreases the reaction rate. The lower oil concentration might be due to the high methanol content (more than the optimal ratio) which is interfered with the phase separation of glycerol due to an increase in the solubility of glycerol in methanol. Therefore, 24:1 is the appropriate methanol/oil molar ratio for this reaction. The excess methanol could be collected and recycled [21].

This study also investigates the effects of catalyst amount on conversion. The catalyst amount varies from 2 to 10% (catalyst/oil weight ratio). As shown in Fig. 2, the catalysts increase the contact opportunity between the catalyst and the reactant, which directly influences the reaction speed and the conversion. However, with a further increase of the loading amount, the conversion has no significant difference. The rational reason is due to the rise of



**Fig. 3.** Influence of the reaction time on the conversion rate (reaction conditions: soybean oil; 12.5 g, reaction temperature; 65 °C, methanol-to-oil ratio 24:1, and catalyst amount 6 %).



**Fig. 4.** The conversion of  $\text{Li}_2\text{TiO}_3$ , CaO and NaOH (Reaction conditions: methanol-to-oil ratio 24:1, catalyst amount 6%, reaction temperature 65 °C and reaction time 2 h).

mixing problem (oil/ methanol/catalyst). Wang et al. [22] also observed similar results when the conversion rate increased with an increase in the catalyst amount. The conversion was found to be maximum at 6 wt% of catalyst loading when compared to 2, 4, 8 and 10 wt% of catalyst loading. This might be due to the formation of more mass transfer produced at higher catalyst loading. So, the excess of mass transfer content might affect the catalyst and the transesterification reaction

Fig. 3 indicates that the conversion is found to increase with the increase in the reaction time from 0.5 to 2 h and then decrease with the increase in the reaction time above 2 h. In Fig. 3, the result suggests that the rate of FAME formation is lower at lower reaction time for the transesterification and increases when the reaction time for the transesterification reaches the maximum value of 2 h. These results indicate that the maximum conversion is 98.5% for  $\text{Li}_2\text{TiO}_3$ . The conversion then decreases probably due to the formation saponification at longer reaction time for the transesterification. The optimized reaction time for the transesterification of soybean oil to biodiesel thus is 2 h.

Fig. 4 shows the experimental results of the soybean oil catalyzed using  $\text{Li}_2\text{TiO}_3$ , Commercially available CaO and NaOH

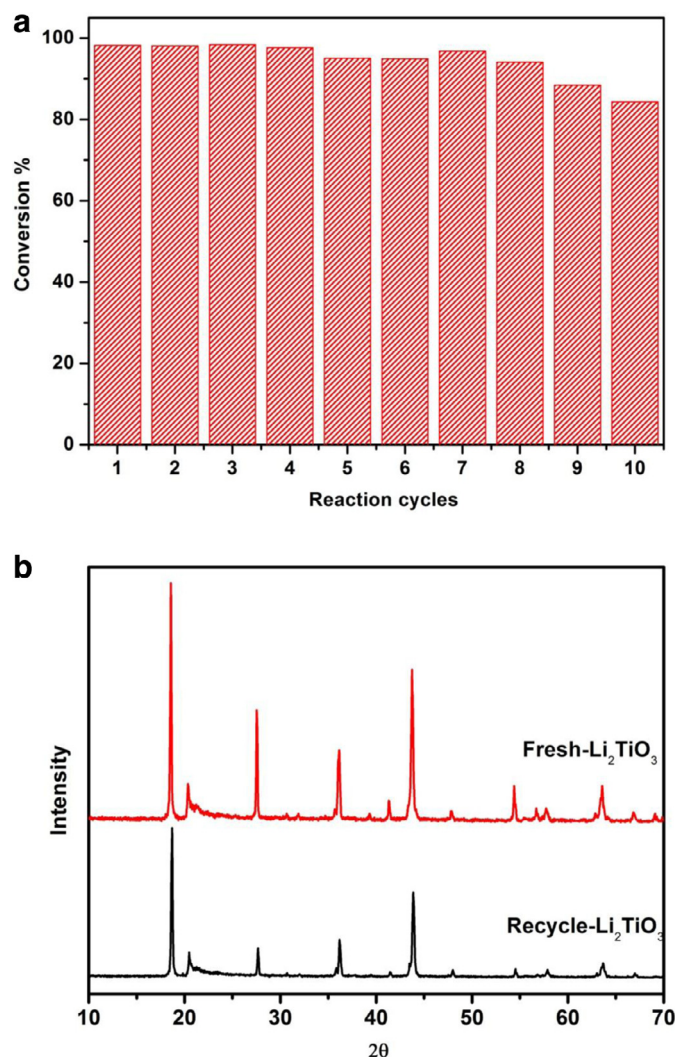


Fig. 5. (a) Reusability of  $\text{Li}_2\text{TiO}_3$  after ten reaction cycles and (b) XRD patterns acquired before and after the transesterification reaction.

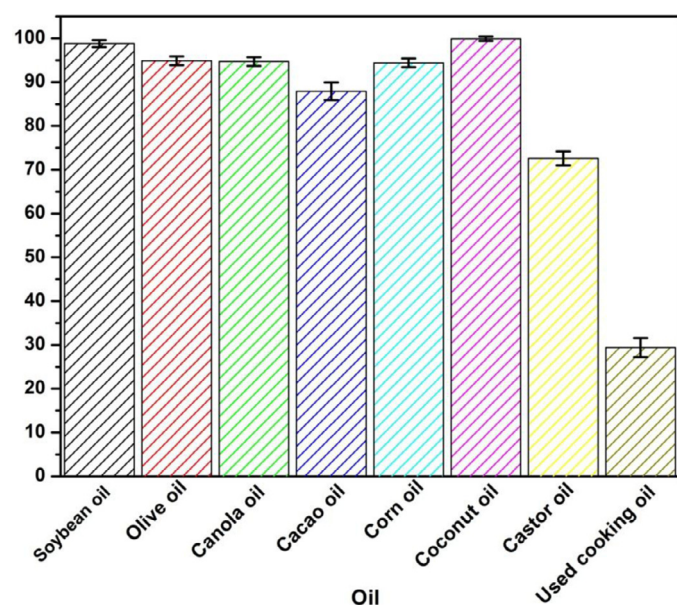


Fig. 6. Conversion comparison of different oil. (Reaction conditions: methanol-to-oil ratio 24:1, catalyst amount 6%, reaction temperature 65 °C and reaction time 2 h).

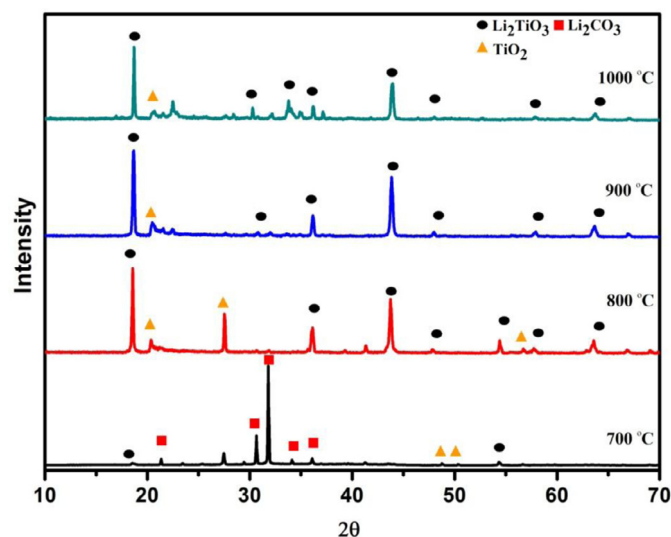


Fig. 7. XRD patterns of the  $\text{Li}_2\text{TiO}_3$  prepared using various calcination temperatures.

Table 1

Base strengths ( $H_-$ ) of  $\text{Li}_2\text{TiO}_3$  and CaO after exposing to air.

Exposure Time(h)	$\text{Li}_2\text{TiO}_3$ Basic strength	Conversion* (%)	CaO Basic strength	Conversion (%)
0	15.0–18.4	98.55 ± 0.87	15.0–18.4	95.2
24	15.0–18.4	97.38 ± 1.12	7.2–9.8	2.9
48	15.0–18.4	95.64 ± 1.09	7.2–9.8	2.5
72	9.8–15.0	88.06 ± 2.11	7.2–9.8	1.3

\* Reaction conditions: methanol-to-oil ratio 24:1, catalyst amount 6 %, reaction temperature 65 °C and reaction time 2 h.

catalysts. All catalysts exhibit high conversion greater than 90%. The descending order of the conversion over the catalysts is ranked as  $\text{Li}_2\text{TiO}_3 > \text{CaO} > \text{NaOH}$ . It is determined that the catalytic activity of the catalysts is not directly related to the surface area, but their base strengths and basicity values, *i.e.* the higher base strengths and basicity values of the catalysts resulting in the higher conversions.

### 3.2. Reusability of catalyst

Table 1 shows the basic strength of the as-prepared catalysts, CaO and  $\text{Li}_2\text{TiO}_3$ , after different exposure time to ambient air. This study investigates the effects of exposure to air on the activity of the transesterification reaction.  $\text{Li}_2\text{TiO}_3$  and CaO appear to have the same initial basic strength. However, the basic strength of CaO decreases significantly following the exposure of the catalysts to air ( $7.2 < H_- < 9.8$ ), thus influencing the conversion. This deactivation is likely the result of being hygroscopic and easy to deliquesce in the air, even after a 24 h exposure to air, when CaO is deactivated [23]. The basic strength ( $H_-$ ) of  $\text{Li}_2\text{TiO}_3$  decreases to 9.8–15.0 after exposure to air for 24–72 h. According to Table 1, no difference appears in the conversion (98.5–88.1%) and the freshly prepared catalyst (98.5%) is observed, verifying that the catalytic sites of  $\text{Li}_2\text{TiO}_3$  are tolerant toward  $\text{CO}_2$  and  $\text{H}_2\text{O}$  contained in air. In contrast to CaO,  $\text{Li}_2\text{TiO}_3$  is a more anti-deliquescent catalyst in the air.

The solubility of the catalysts is also a critical factor to consider in appropriately interpreting their performance and assessing their potential practical application. According to Table 2, the first transesterification reaction produces oil containing 0.28 ppm of  $\text{Li}^+$ . Repeating the process between one to four times maintains the different using times being all below 0.5 ppm. The catalytic results reveal that the  $\text{Li}_2\text{TiO}_3$  catalyst maintains its activity after 5 catalytic runs (Table 2). It clearly indicates the advantage of solid-base

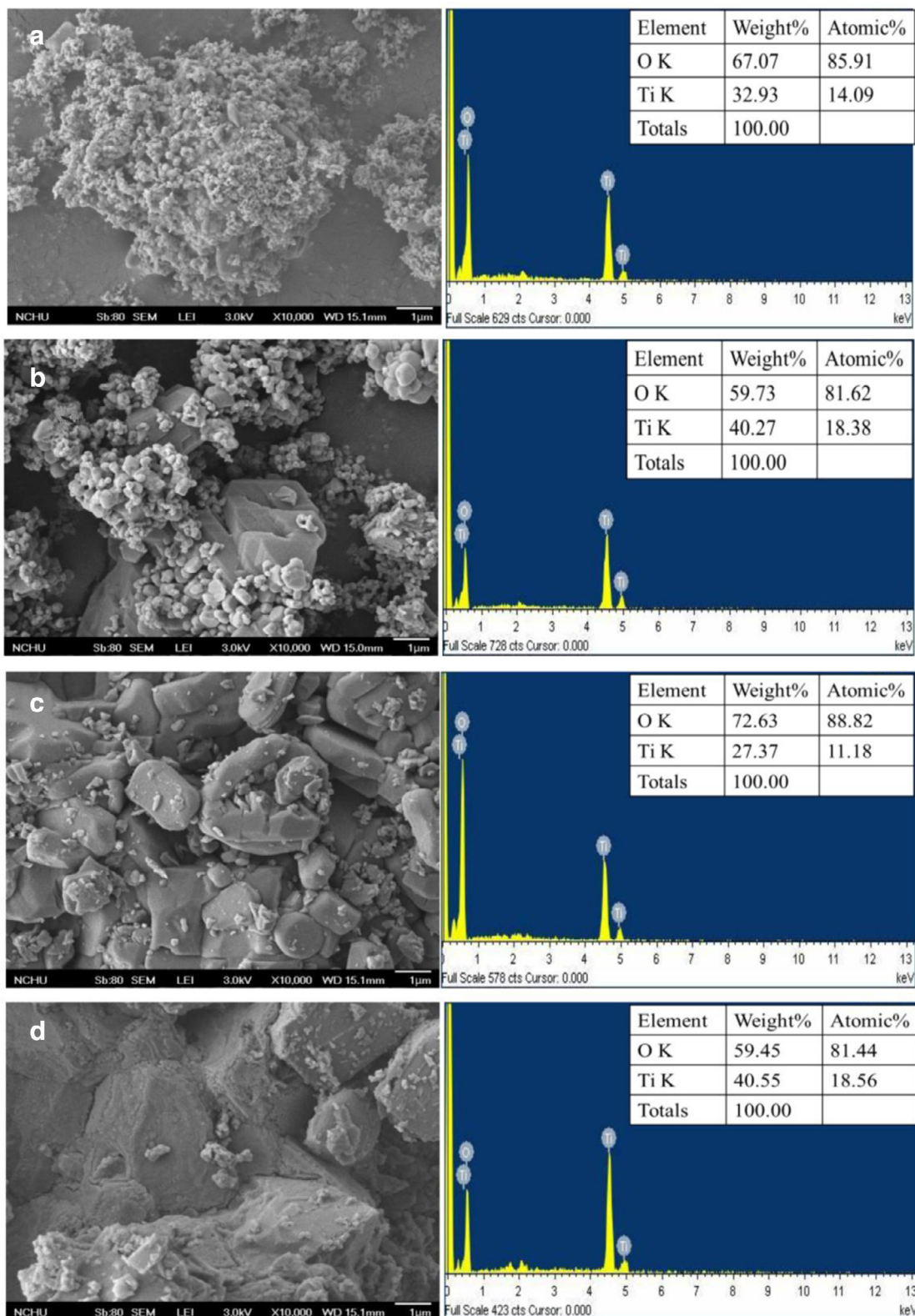


Fig. 8. FE-SEM images and EDX of the  $\text{Li}_2\text{TiO}_3$  prepared with various calcination temperatures. (a) 700 °C, (b) 800 °C, (c) 900 °C, (d) 1000 °C.

catalyst for the reaction stability and the possible feasibility. After the 5 catalytic runs, the biodiesel yield remains close to 94.8%. The results show that the conversion decreases by 94.8% compared with that of fresh catalyst; so, it can be concluded that the slight decline of activity is due to more  $\text{Li}^+$  being leached into the biodiesel. These results demonstrate that extremely small quantity

of  $\text{Li}^+$  exists in the biodiesel. The results indicate that the prepared  $\text{Li}_2\text{TiO}_3$  catalyst is stable for the use in the biodiesel production from soybean oil.

The durability of  $\text{Li}_2\text{TiO}_3$  is evaluated by recycling the used catalyst. No apparent loss is observed in the catalytic activity when converting soybean oil into biodiesel in the ninth cycle; even

**Table 2**  
Reusability study after 5 reaction cycles for  $\text{Li}_2\text{TiO}_3$  catalyst.

Catalyst use time	Concentration of $\text{Li}^+$ (ppm)	Conversion (%) <sup>a</sup>
1	0.28	98.2 ± 0.87
2	0.33	98.1 ± 0.75
3	0.36	98.5 ± 1.14
4	0.35	97.6 ± 2.13
5	0.52	94.8 ± 2.07

<sup>a</sup> Reaction conditions: methanol-to-oil ratio 24:1, catalyst amount 6%, reaction temperature 65 °C and reaction time 2 h.

during the tenth run, the decrease in the conversion is 15% (Fig 5(a)). The used  $\text{Li}_2\text{TiO}_3$  is also examined using XRD and no detectable difference is observed between the as-prepared and used samples (Fig. 5(b)); thus,  $\text{Li}_2\text{TiO}_3$  has high catalytic activity to promote the transesterification reaction.

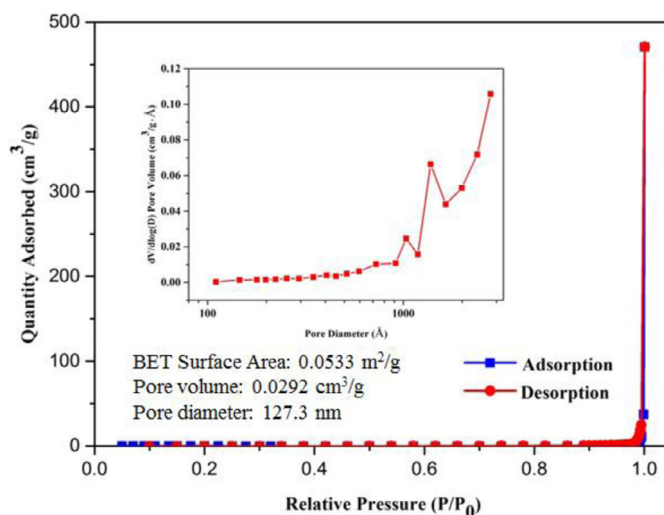
### 3.4. Optimization of reaction parameters for different oil using catalyst

The percentage conversion of different oil into biodiesel is shown in Fig. 6. The conversion of soybean oil, olive oil, canola oil, cacao oil, corn oil, coconut oil, castor oil and used cooking oil into biodiesel were found to be 98.5%, 94.9%, 94.7%, 87.9%, 94.4%, 99.2%, 62.5%, 72.2 and 29.4%, respectively. The oil containing high free fatty acid, such as oleic acid, was used for producing biodiesel. The free fatty acid concentration of the feedstock was higher than the alkali catalyst should not be used in the transesterification reaction due to the soap formation [24], which was highly undesirable. Apart from that, high water content in waste cooking oil also affected the methyl ester yield. When water was present, particularly at high temperature, it could hydrolyze triglycerides to diglycerides and form free fatty acid. Thus, when water was present in the reactant, it generally manifested itself through excessive soap production. The result showed castor oil and used cooking oil with high free fatty acid that the conversion was affected much for the  $\text{Li}_2\text{TiO}_3$  examined.

### 3.5. Characterizations of as-prepared catalyst

The XRD spectra results for the calcination temperature ranging from 700 to 1000 °C for  $\text{Li}_2\text{CO}_3/\text{TiO}_2$  molar ratio of 2 are shown in Fig. 7. When the calcination temperature reaches 700 °C, there are diffraction peaks in  $\text{Li}_2\text{CO}_3$  (JCPDS 87-0728). Upon the calcination at 800 °C, this is possibly resulted from the complex reactions between Li and Ti compounds;  $\text{Li}^+$  is sucked into the gap in the Ti compound crystal layers and reacts with  $\text{Ti}^{2+}$  to produce  $\text{Li}_2\text{TiO}_3$  (JCPDS 75-1602). With the increasing calcination temperature, the peak intensity of the  $\text{Li}_2\text{TiO}_3$  phase increases. When the calcination temperature reaches 900 °C, there are stronger diffraction peaks of the  $\text{Li}_2\text{TiO}_3$  phase. The results show that the higher the calcination temperature, the higher the conversion is achieved with  $\text{Li}_2\text{TiO}_3$ . The increasing calcination temperature leads to the crystallization of the catalyst into a new structure. It is possible that the presence of Li–O–Ti species, where the metals are in close interaction, results in a more active layer of surface sites, which in turn leads to higher conversion. The data are not conclusive on this point; it can be speculated that Li–O–Ti is much more active site [14,25].

Fig. 8 shows the FE-SEM image of the catalyst prepared by changing the temperature ranging from 700 to 1000 °C. The catalyst is prepared with grinding  $\text{TiO}_2$  and  $\text{Li}_2\text{CO}_3$  by the solid-state reaction. In Fig. 8(a)  $\text{TiO}_2$  and  $\text{Li}_2\text{CO}_3$  calcined at 700 °C, a lot of  $\text{Li}_2\text{CO}_3$  still exist and keep their microstructure. Some homogeneous small mineral aggregates have very rough surface. In Fig. 8(b), sheet needle aggregates and agglomerated particles are



**Fig. 9.** Nitrogen adsorption–desorption isotherm and pore size distribution of the catalyst.

present when the calcination temperature increases because of the formation of the  $\text{Li}_2\text{TiO}_3$  phase. Fig. 8(c) shows the sheet needle of the 900 °C morphology ranging between 10 and 100  $\mu\text{m}$ , which could accommodate the extrinsic surface water or other adsorbates. Fig. 8(d) presents FE-SEM images at 1000 °C. The surface starts to agglomerate and gradually shape lumps and agglomerate blocks.

Fig. 9 shows the nitrogen adsorption–desorption isotherm curves, showing the as prepared  $\text{Li}_2\text{TiO}_3$  by the solid-state reaction at 800 °C. The isotherms of  $\text{Li}_2\text{TiO}_3$  follow the type IV and are shown with a hysteresis loop at a high relative pressure between 0.6 and 1.0 [26], indicating a typical mesoporous structure. The shape of the hysteresis loop is close to Type H3, suggesting the existence of slit-like pores generally formed by the aggregation of irregular thin sheets to irregular thin plates. Moreover, one should note that the catalysts calcined at high temperatures have a much lower surface area, shown in Fig. 9. It is determined that the catalytic activity of the catalysts is not directly related to the surface area, but the catalytic activity of the catalysts agrees well the basic strength generated during the active Li–O–Ti sites increases with the calcination temperature. It can be speculated that the presence of megaporous structure, with the large megaporous, would minimize the diffusion limitations of molecules with long alkyl chains [27].

## 4. Conclusion

The  $\text{Li}_2\text{TiO}_3$  catalyst is studied and applied to the transesterification of soybean oil into biodiesel. Several reaction variables are studied, where the optimal catalyst loading into the reaction media is 6% (w/w) and the methanol/oil molar ratio of 24:1 produces the highest conversion.  $\text{Li}_2\text{TiO}_3$  could be repeatedly used for more than 5 runs and is air-insensitive. This biphasic system enables products to be easily separated from the catalyst and shows good recyclability. In addition, this is one of the most effective catalytic systems available for improving biodiesel by using  $\text{TiO}_2$  and a  $\text{Li}_2\text{CO}_3$  composite.

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