Biodiesel Fuel (BDF) Synthesis by using Ion Exchange Resin Based on Ultrasonic Irradiation and Its Application

Ning. Zhu¹*, Mingchi Kuo² and Chung Hsin Han²

¹Shizuoka Institute of Science and Technology, 2200-2 Toyosawa, Fukuroi, 4378555, Japan
²Graduate School of Shizuoka Institute of Science and Technology, 2200-2 Toyosawa, Fukuroi, 4378555, Japan

* Corresponding Author: Ning Zhu: zhuing@me.sist.ac.jp, Tel:+81-538-450232, Fax: +81-538-450120

Abstract

Ultrasound irradiation with NaOH proved an important method in catalyst to synthesize BDF. However, the synthesis of BDF remains a major challenge since a large quantity of water is needed to wash the BDF after it is produced. It is now well established from a variety of studies, that solid catalysis does not need a large quantity of water to wash the BDF after its production. The concept of zeolites is used as solid catalysts to synthesize BDF and BDF and its ratio yields up to 62%. This study uses ion exchange resin (henceforth, IER) as the catalysts for BDF production. Firstly, this research examines the emerging role of IER in the increase of its basic characteristics. Secondly, the prepared IER is characterized using SEM and X-ray diffractometer. Thirdly, the BDF synthesis experiment is carried out using the prepared IER based on ultrasonic irradiation. Finally, diesel engine performance test is carried out to investigate the thermal efficiency and exhaust gas concentration. The current study found that BDF yield ratio reached 44.4% when IER was prepared under the condition of 6mol NaOH preparation.

Keywords: BDF synthesis, Solid catalyst, Ultrasonic irradiation, Exhaust gas concentration

1. Introduction

Exposure to global warming and energy crisis has been shown to be related to adverse effects in drastic economic development and large quantity usage of fossil fuel. However, biodiesel fuel (henceforth, BDF) could be a contributing factor to alternative fuel for the automobile. There is a growing body of literature that recognises methods of synthesizing BDF and its applications [see 1-8]. There is some evidence to suggest that BDF comes from vegetable oil so that it is clean and sustainable. It can be also used for any automobiles with diesel engines. Due to the support and being promoted from the EU and the USA government, recent trends in the application of BDF have led to a proliferation of studies that BDF can be used as B5 or B10. However, a major problem with this kind of application in Japan is only 100% BDF is permitted to be used on diesel automobiles. While the production cost of the BDF is considerably higher than diesel fuel and it declines in the wide use of BDF. Studies over the past
two decades have provided important information on employing ultrasound irradiation with NaOH as the catalyst to synthesize BDF. One major issue in early BDF research concerned a large quantity of water is needed to wash the BDF after it is produced. However, far too little attention has been paid to the development of a new method based on the solid catalysis because it can decrease water-washing in the production. Existing research recognises the critical role played by zeolites as solid catalysts to synthesize BDF and BDF and its yield ratio is up to 62%. Rather, this paper proposes a new methodology for using IER as the catalysts for BDF production. Firstly, ion exchange resin is prepared to increase its basic characteristics. Secondly, prepared IER is characterized by using SEM and X-ray diffractometer. Thirdly, the BDF synthesis experiment is carried out by using the prepared IER based on ultrasonic irradiation. Finally, diesel engine performance test is carried out to investigate the thermal efficiency and exhaust gas concentration. This study showed that the BDF yield ratio reached 44.4% when IER was prepared under the condition of 6mol NaOH preparation.

2. A principle of BDF synthesis
Figure 1 presents the BDF synthesis principle of using IER as the catalyst to produce. Vegetable oil (triglyceride) was then mixed with alcohol (methanol) at proper ratio under the condition of ultrasonic irradiation for some time. When a transesterification reaction was carried out, the BDF and the by-product of glycerin was yielded.

![BDF synthesis principle](image)

Figure 1. BDF synthesis principle

3. An experiment of BDF synthesis

3.1 Catalyst preparation and evaluation
In this paper, the IER used for BDF synthesis was called ORGANO. IR120B NA and its specifications are set out in Table 1.

| Construction | Classification | Ion form | Mean diameter (mm) | Operating temperature (°C) | Effective PH range |
|--------------|----------------|----------|--------------------|-----------------------------|-------------------|
| styrene      | strong acidity | Na⁺ / H⁺ | 0.60 ~ 0.80        | 120                         | 0 ~ 14            |

Table 1. IER model number
Figure 2 shows the size and shape of the IER and its SEM analysis before preparation. IER has the round shape whose average external diameter is around 0.6-0.8 mm, which are smaller than zeolites. According to the SEM analysis result, the surface area of IER is very large, which could absorb a large amount of liquid.

![IER and SEM analysis](image)

**Figure 2.** The shape of IER and its SEM analysis before preparation.

Since base strength could properly influence the BDF yield ratio, before BDF synthesis, IER was prepared as follows:

Step 1: Soak samples of IER with different NaOH or CaOH concentration (6 and 9 mol) for 24 hours
Step 2: Wash the samples by using methanol and then dry the samples
Step 3: Sinter the samples by an electric furnace at the temperature of 100°C for two hours

After IERs were prepared, SEM was used to investigate the changed quantity of Na+ that was added to the IER. An X-ray diffractometer is used to characterize their base strength characteristics.

### 3.2 A synthesis of BDF

Prior to batch type BDF synthesis, the mixture of the reactants of vegetable oil and methanol was prepared inside a glass tube, which is immersed into the ultrasonic reactor (called Hondex) with hot water (see Figure 3). Then, the power of the ultrasonic reactor was switched on at frequency of 28 kHz. From the data of BDF synthesis in Table 2, it is apparent that the IER was used as the solid catalyst while the Zeolite A5 is also used for BDF synthesis.

| Table 2. BDF synthesis condition |
|----------------------------------|
| Volume ratio of vegetable oil to methanol | 5:1 |
| Methanol purity | 99.5% |
| Catalyst | IER & Zeolite A5 |
| Quantity of Ion exchange resin | 0.33wt% |

![BDF synthesis](image)

**Figure 3.** BDF synthesis by using a batch method
After BDF synthesis, BDF components are detected and BDF yield ratio is measured by GCMS (Shimadzu GCMS-QP2020).

4. Engine performance test and exhaust gas concentration
A small diesel engine (called KM170F) was used to obtain an engine performance test from the thermal efficiency and the exhaust gas concentration. The specification of the engine is listed in Table 3. The main advantage of the testing is that it is to confirm the possibility of using 100% BDF or the mixture of BDF with diesel fuel. The results obtained from the engine performance test experimental system are shown in Figure 4. This system consists of the diesel engine, fuel flow meter, fuel tank, electric load, revolution indicator and Watt indicator. After the engine is started, the first step in this process was to adjust the revolution number to 3300 rpm under an electric load of 500W, 1000W, 1500W and 2000W, respectively. Then, fuels of BDF with different mixture ratio (0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% to 100%) was used. After the fuel consumption rate, output power, intake temperature, exhaust temperature, exhaust gas concentrations (e.g. smoke, CO and NOx) were measured, the engine thermal efficiency was calculated.

5. Results and discussions

5.1 Catalyst evaluation
It was found that Na+ content change after the preparation of IER, as illustrated in Figure 5. Based on the SEM analysis, it is also found that the Na+ content increased when the preparation with higher NaOH concentration was used. In the case of IER with 6mol and 9 mol NaOH, the Na+ content was in a range of 16.8% and 22.2%.
Before the preparation, the Na+ content was only under 12%. It revealed that the preparation has increased the Na+ content and enhances the basic strength. Figure 6 presents an X-ray diffractometer. Further analysis showed that the forms are similar to general IER, prepared IER. However, there was a slight change in the strength. It is apparent that the structure of IER of before and after preparation did not show a significant difference. There was a slight change of the strength with the influence of the liquid NaOH.

5.2 BDF synthesis
BDF synthesis result is demonstrated in Figure 7. It is observed that BDF could be produced under the condition of using IER with 6mol NaOH and A5 Zeolite with 6mol NaOH as the catalyst, respectively. While less BDF was produced for IER with 6 mol CaOH preparation. To compare the photos of the BDF produced by using a different catalyst, BDF yield ratio was 41.4% for IER catalyst, and it appeared to be no higher than the zeolite. It was also found that that the broken zeolite under ultrasonic irradiation might strengthen the BDF synthesis reaction and increase the BDF yield ratio.
Figure 7. BDF synthesis result

Figure 8. Thermal efficiency
5.3 Results of engine performance test

As can be seen from Figure 8, it reported the efficiency of the thermal under different electric load for a different mixture of BDF to diesel fuel. Further analysis showed that its efficiency was around 21% for all the experimental conditions. Thus, the lower the fuel mixture ratio of diesel fuel to BDF, the higher the thermal efficiency. In the case of 100% diesel fuel, the efficiency of the thermal reached 21.4% while in the case of 100% BDF, the thermal efficiency was by 17.4%.

Smoke concentration in the form of the optical absorption coefficient for the electric load of 0w and 2000W is shown in Figure 9. With the higher electric load, the Smoke concentration would increase rapidly. But in the case of 100% BDF, there was a slight decrease in the smoke concentration (0W electric load).

Figure 10 provides a CO concentration. With more percentage of BDF, CO concentration would decrease due to extra oxygen brought by the BDF contained the generation of CO. However, for the load of 1500W, CO concentration appeared to be the lowest for each experimental condition. It can thus be suggested that the best air-fuel ratio was observed for the electric load of 1500W.

NOx concentration is shown in Figure 11. With higher electric load, the NOx concentration would become higher because the higher electric load lead to the larger consumption of fuel. It is possible, therefore, that the increase in temperature of the combustion may be due to the increase in the generation of NOx. In case of higher ratio of BDF to diesel fuel, it seems that the NOx concentration tended to increase to some extent. This may be explained by the influence of the extra oxygen coming from BDF, which increased the combustion temperature.

![Figure 9. Smoke concentration for electric load of 0w and 2000W](image_url)
Figure 10. CO concentration

Figure 11. NOx concentration
6. Conclusion
This study has identified the method of using IER as the catalyst for BDF synthesis using IER preparation and BDF synthesis experiment. The mixture fuel of different ratio of BDF to diesel was also used for engine performance test and thermal efficiency, as well as the exhaust gas concentration was measured. This study has shown that the prepared IER of 6 mol NaOH, BDF yield ratio reached 41.4%. These experiments confirmed that the efficiency of the thermal was around 21% for each experimental condition. With a higher ratio of BDF to diesel fuel, the smoke concentration and CO concentration would become lower and NOx concentration became higher.

References
[1] Furugawa S Shimada M Okada M Hirobashi L Szuki Y 2004 Proc. Japan Chemical Society (Japan) 84(2) 1295-1296
[2] Dszuki T Hanehara H Chita J 2005 Proc. JSME of Kansai Branchy Conference (Japan) 80 1247-1248
[3] Yamane K Shimamoto J Ueda J 2001 Transactions of JSA 32(2) 25-30
[4] Yamane K Shimamoto J Inoue H 2001 Proc. JSME of Kansai Branchy Conference (Japan) 76 1249-1250
[5] Furuta S Matsuhashi H Arata K 2004 Journal of Catalysis Communicationse 5(12) 721-723
[6] Zhu N Tsuchiya T Ito N Kato N 2005 Proc. 3rd International Energy Conversion Engineering Conference 5543
[7] Zhu N Guo M C Zhang T C 2017 Proc. the 8th Thailand Society of Mechanical Engineers International Conference on Mechanical Engineering (Bangkok:Thailand)
[8] Zhu N Guo M C Zhang T C 2018 Proc. the 9th Thailand Society of Mechanical Engineers International Conference on Mechanical Engineering (Phuket:Thailand)