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Predicting biodiesel production using biomass derived waste kiwifruit ash as heterogeneous catalyst

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Abstract: Waste biomass derived catalysts have been receiving considerable interest recently as a heterogeneous catalyst for the synthesis of biodiesel since it can be recycled in production processes and doesn't cause soap to form. This study looked at the catalytic activity of waste kiwifruit ash as a catalyst to make biodiesel from waste soybean cooking oil transesterification. It was found that the ash from dried and burned waste kiwifruit may serve as a heterogeneous catalyst for the synthesis of biodiesel that was both economically and environmentally friendly. By using TGA, WD-XRF, and XRD, the synthesised catalyst was analysed. Using reaction conditions at 65 °C for 60 minutes, a 2 wt% catalyst dosage, and a 10:1 methanol to oil molar ratio, waste soybean cooking oil was transformed to biodiesel with a yield of 91 %. The reaction product is confirmed by utilising the GC method. Studies on recycling concluded that the produced catalyst retained a high activity up-to three cycles.

Keywords - Kiwifruit ash; waste; heterogeneous catalyst; biodiesel; transesterification; waste soybean cooking oil

1. INTRODUCTION

The need for renewable energy sources has grown as the supply of fossil fuels is depleting and environmental pollution linked to the consumption of fossil fuels is becoming a bigger concern. Global warming, ozone layer depletion, and problems related to climate change are all caused by emissions from the burning of fossil fuels [1]. As a result, new energy sources that are ecologically benign, efficient, relatively cheap, and renewable have been getting a lot of attention. Most of these characteristics are inherent characteristics of biofuels, which include biogas, bioethanol, and biodiesel [2]. Out of all of these biodegradable fuels, biodiesel appears to have the requisite physicochemical characteristics that are comparable to those of conventional diesel [3].

Biodiesel is a generic term of fatty acid methyl esters (FAME), which can result from a transesterification reaction. This process uses a variety of oil sources, including both edible and non-edible oils, waste vegetable oils, animal fats, and micro-algal lipids as feedstock in addition to a short chain of alcohol, often methanol/ethanol in the presence of a catalyst to produce biodiesel. As a heterogeneous catalyst, biomass-derived ash has been employed experimentally to speed up the reaction and transform triglycerides into biodiesel and glycerol. The idea that biomass-derived catalysts are renewable and sustainable, as opposed to conventional catalysts like NaOH/KOH, minimises the environmental impact of the production of biodiesel. They are regenerable and reusable several times, which lowers the cost of making biodiesel. The process of making these ash catalysts usually comprises drying, burning, and calcining biomass at temperatures between 300 °C and 900 °C to produce solid mixed oxide catalysts for the reaction. In order to obtain ash from the waste kiwifruit that could be used practically to produce biodiesel, kiwi was first dried in the sun, then air burned, and finally calcined at 700 °C in this study.

The kiwifruit biomass has the potential for being utilized to produce biodiesel. According to the most recent data, the world produces 4 million tonnes of kiwifruit annually, with China accounting for half of that total [4, 5]. Asia is the primary producer. In particular, even while this fruit is commonly consumed fresh, it is also used to make products like juices, wines, jams, and ice cream, among others [6]. As a result of this commercialization, leftover kiwifruit is produced, primarily the seeds, skin, and kiwifruit waste, all of which have the potential to be useful energy sources. The kiwifruit residues could, among other things, be employed again as natural additives or useful components in the food and pharmaceutical industries. Although having alkali and alkali earth metals in their elemental composition, which suggests its ability as a catalyst to convert oil into biodiesel, kiwifruit ash's catalytic activity in transesterification has not yet been studied. For it to be viable for commercial-scale production, more study is required.

This study examined the use of kiwifruit ash as a heterogeneous catalyst and its catalytic activity in the production of biodiesel. Further research was done into how the calcination temperature and methanol to oil molar ratio impacted the catalytic efficiency of the produced materials. The obtained catalyst's recyclability was investigated in order to produce biodiesel by the transesterification of waste soybean cooking oil. The favourable findings encouraged the researchers to carry on with their research on the kiwifruit-based catalysts.

2. CATALYST PREPARATION AND ITS CHARACTERIZATION

Waste kiwifruit were collected for the catalyst preparation, and after being thoroughly cleaned with tap water to eliminate contaminants, they were exposed to the sun for 12 days to dry. The kiwifruit were then ground into a powder and burnt in the air to create an ash catalyst. Furthermore, it was calcined at 800 °C for 4 hours in order to activate the catalyst. The catalyst was recalcined at 800 °C for each cycle of the test to determine its suitability for reuse.

The prepared ash catalyst was characterized by X-ray fluorescence (WD-XRF, PANalytical spectrometer) to evaluate its compositional elements. Using an X-ray powder diffractometer (XRD, 5th-generation Rigaku) the crystalline phases of the ash catalyst are studied. And a thermogravimetric analysis (Shimadzu TGA50 series) was employed to measure the thermal behaviour of the ash catalyst.

3. TRANSESTERIFICATION PROCESS AND ITS CHARACTERIZATION

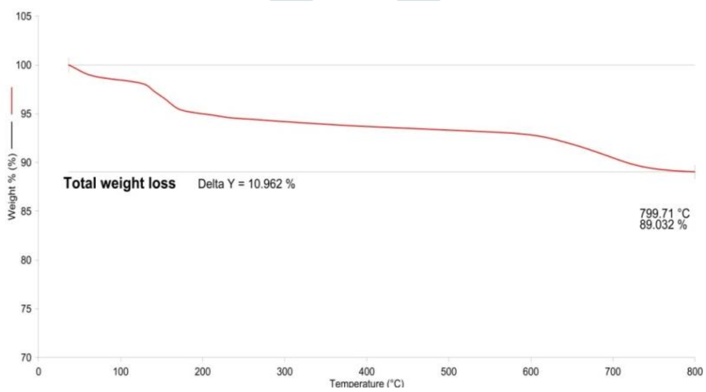
Trans-esterification is a procedure that is used to convert vegetable oils or animal fats in order to increase the volatility and decrease the viscosity of engine fuel. Waste soybean cooking oil was heated to 100 °C using a hot plate magnetic stirrer to remove the water content. Methoxide is then added to the hot oil, which is a mixture of methanol and ash catalyst. In this experiment, kiwifruit waste is employed as a catalyst amounting 2 wt%, methanol to oil ratio 10:1 at 65 °C. A magnetic stirrer is used to agitate the oil and methoxide mixture at 1400 rpm while maintaining a temperature of 65 °C. Following an one hour of reaction completion time, after that a separating funnel was used to separate the biodiesel and glycerol mixture. Biodiesel has a low density, which causes it to float above glycerol in the lower phase. Afterwards, using gas chromatography (GC) study, the produced biodiesel was characterised. The catalytic assessment of the ash is seen when various calcination temperature, catalyst loadings and methanol to oil ratios are used.

4. RESULT AND DISCUSSIONS

4.1 TGA ANALYSIS

By TGA analysis, the temperature behaviour of the ash catalyst was examined as seen in fig 1. The initial stage of the weight loss happened below 200 °C because kiwifruit ash is a carbonaceous compound, and this temperature range relates to the drying, which entails the removal of water and mild volatile matter while the stable structure did not disintegrate. And a second stage of the significant weight loss occurred at 800 °C, at temperatures over 800 °C, no weight loss was seen. Hence, the temperature of 800 °C could be chosen for the calcination of the ash catalyst because it was known that the majority of carbon species were decomposed in the range 400 °C - 800 °C in the air [7]. Specifically, the calcination temperature exceeding 900 °C had a detrimental effect on the catalytic activity while temperatures lower than 800 °C was insufficient to convert biomass carbonates into its solid oxides.

Figure 1: TGA graph of calcined waste kiwifruit ash



4.2 WD-XRF ANALYSIS

In Table 1, the results of the WD-XRF analysis of the inorganic elements that are found in waste kiwifruit ash are presented. Many elements, notably K, Ca, Mg, P, Cl, S, Na and others were identified as producing the phases that gave catalysts their catalytic activity. As shown in Table 1, some transition metal oxides also coexisted in minute levels with these metal oxides. As a result of the findings, we can say with certainty that K, primarily in the form of KCl, and K_2CO_3 is the main basic metal responsible for the catalytic activity in the transesterification reaction to make biodiesel [8], as demonstrated by XRD analysis also.

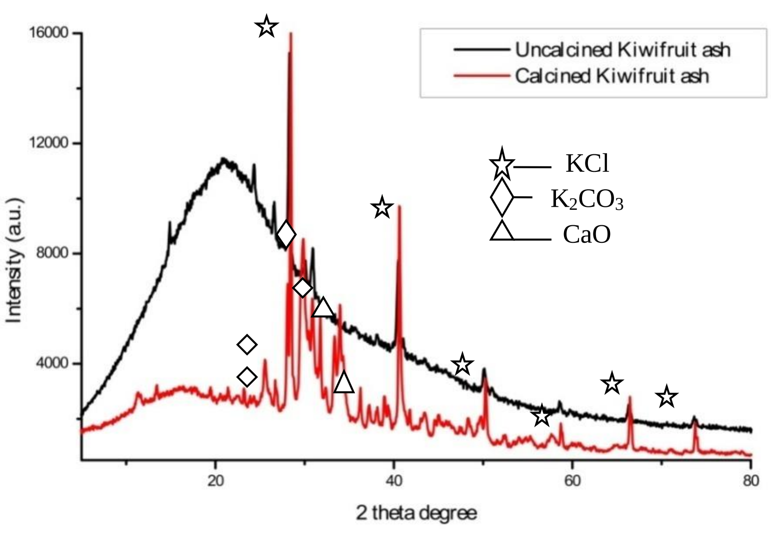
Table 1: Metallic and non metallic eliments in calcined kiwifruit ash catalyst

S. No.	Name of the elements	Concentration (%)
1	K	56.034
2	Ca	14.749
3	Mg	7.586
4	P	6.552
5	Cl	5.027
6	S	3.132
7	Na	3.128
9	Fe	2.238
10	Zn	1.012
11	Al	0.216
12	Si	0.211
13	Mn	0.115

4.3 XRD ANALYSIS

In fig. 2, the XRD pattern of calcined and uncalcined waste kiwifruit ash is displayed. Uncalcined kiwifruit ash was partially burned to produce the substance of the structure, which appeared to be amorphous. But following calcination and the elimination of carbonaceous and volatile materials, a multiphase crystalline system was created, and this calcined ash catalyst was made of several potassium compounds, including KCl and K_2CO_3, which are the dominant elements in the reaction process, as well as other oxides, such as CaO also present. The crystalline phase compositions of KCl (JCPDS file no. 41-1476), K_2CO_3 (JCPDS file no. 87-0730), and CaO (JCPDS file no. 82-1691) were observed based on the XRD pattern. Hence, it concluded that the ash catalyst contains a variety of basic oxides and carbonates of K and Ca, which is responsible for transesterification reaction.

Figure 2: XRD pattern of uncalcined and calcined waste kiwifruit ash



4.4 BIODIESEL ANALYSIS

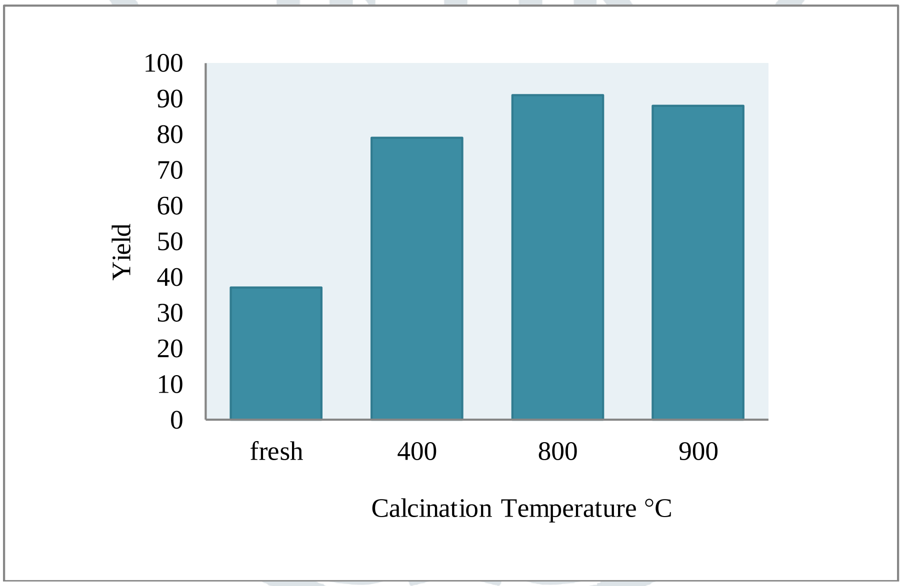
The GC method was used to characterise the produced biodiesel. As a result, fatty acid methyl esters with the following compositions were produced: 14.40% methyl palmitate, 0.67% methyl stearate, 32.16% methyl oleate, 47.73% methyl lionoleate, 7.85% methyl linoleate, and 0.69% methyl arachidate. The density (at 15 °C) and viscosity (at 40 °C) of biodiesel were found to be 0.87g/cm^3 and 4.8 cSt, respectively, which are comparable to standards as per ASTM test procedures.

5. CATALYTIC ACTIVITY OF KIWIFRUIT ASH CATALYST

5.1 EFFECT OF CALCINATION

To study the effect of calcination temperature on the catalytic activity of the kiwifruit ash catalyst, fresh, 500 °C and 800 °C temperature were utilized. The results of the investigation shown in fig 3, indicates that kiwifruit at 800 °C shows high conversion yield 91.4% and above of this temperature shows negative effect this may be because of the carbonate concentration of the metals in the catalyst decrease and accordingly activity for the reaction decreases.

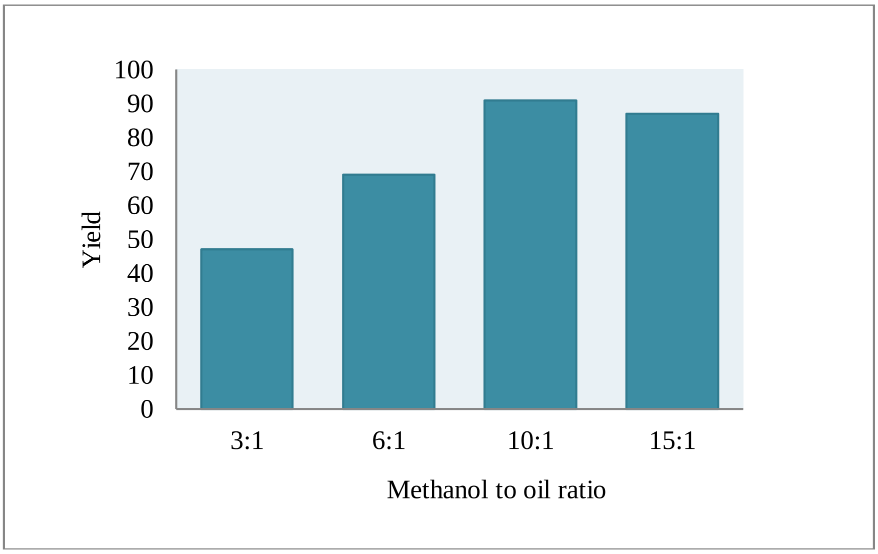
Figure 3: Effect of calcination temperature [reaction condition: catalyst amount 2 wt%, methanol to oil ratio 10:1, temperature 65 °C, reaction time 1 hour]



5.2 EFFECT OF METHANOL TO OIL RATIO

As shown in fig. 4, the effect of varying the methanol to oil ratio from 3:1 to 15:1 was tested. We noticed a significant increase in the biodiesel production yield 91% when the methanol to oil ratio was raised to 10:1. Nevertheless, due to high methanol amounts in the reaction mixture, reversible reactions take place when the methanol to oil ratio is over 10:1, generating monoglycerides and diglycerides, which has a negative impact on the conversion rate of oil to biodiesel [8].

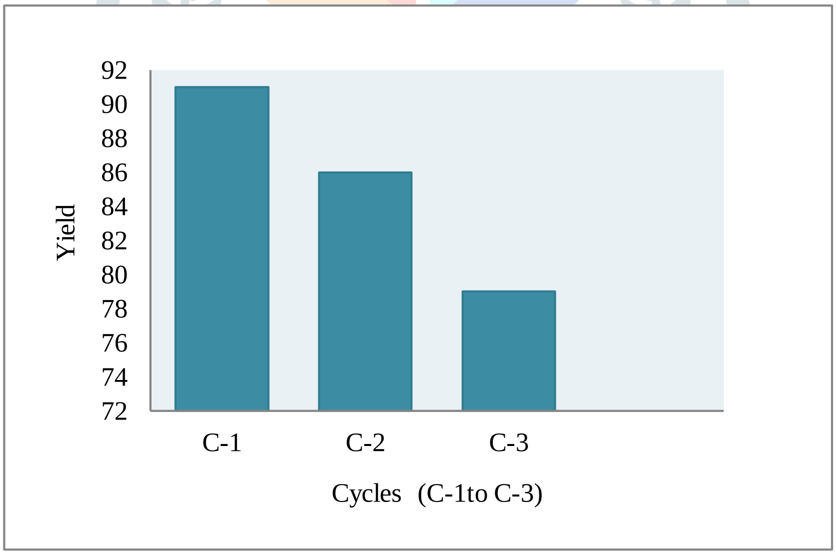
Figure 4: Effect of methanol to oil ratio [reaction condition: catalyst amount 2 wt%, temperature 65 °C, reaction time 1 hour]



5.3 RECYCLABILITY OF THE CATALYST

In this work the kiwifruit ash catalyst catalytic activity was examined by cheeking its reusability displayed in fig 5. It was noted catalyst recycled and reused three times as it was recovered easily maintaining the biodiesel yield under the reaction condition of temperature 65 °C, catalyst amount 2 wt %, methanol to oil ration 10:1 for 1 hour reaction time.

Figure 5: recyclability of the waste kiwifruit ash catalyst [reaction condition: catalyst amount 2 wt%, methanol to oil ratio 10:1, temperature 65 °C, reaction time 1 hour]



6. CONCLUSION

This study aimed at developing a waste kiwifruit ash catalyst for the biodiesel production from waste soybean cooking oil. The catalyst that was calcined at 800 °C performed much better, yielding 91.4% in 1 hour of reaction time at 65 °C, methanol to oil ratio of 10:1, and catalyst amount of 2 wt%. The catalyst had a more basic character due to the high K content, which is necessary for the production of biodiesel because it is found in the forms of KCl and K_2CO_3. Hence, waste kiwifruit ash catalyst prepared in an inexpensive manner offers a better and environmentally friendly catalyst for commercial biodiesel synthesis. Further research is needed to determine whether using kiwifruit waste as a catalyst to produce biodiesel is economically feasible.

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