

Sulfur-Modified Palm Kernel Shell-Derived Porous Carbon for Ethyl Levulinate Synthesis from Ethanol and Levulinic Acid

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Abstract. Biodiesel replacement for diesel remains the most viable solution for achieving net-zero emissions in heavy-duty and/or long-haul transportation. Ethyl levulinate, a derivative of levulinic acid is an additive that improves biodiesel properties. Typical acid catalysts such as hydrochloric acid and sulfuric acid are highly effective and low-cost for esterification, but they are nonreusable and difficult to separate. In this work, sulfur-modified porous carbon derived from palm kernel shell was developed as a reusable heterogeneous catalyst for the esterification of levulinic acid with ethanol to produce ethyl levulinate. Sulfur-modified carbon was prepared by sulfonating porous carbon with sulfuric acid at different concentrations (10, 30, and 50 wt.%), while a fixed catalyst particle size of 0.300–0.355 mm was employed. The catalysts were characterized using scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), nitrogen adsorption–desorption analysis (BET), Boehm titration, and thermogravimetric analysis (TGA). The effects of sulfuric acid concentration on pore characteristics, acid density, and catalytic performance were then evaluated. It is noted that the sulfuric acid concentration affected the pore structure and acid density. The catalyst sulfonated with 30 wt% sulfuric acid exhibited the highest reaction rate constant ($0.014 \text{ mL mmol}^{-1} \text{ h}^{-1}$), while sulfur-modified porous carbon achieved approximately 73% conversion of levulinic acid after 120 h under mild reaction conditions and remained reusable with only a moderate decline in catalytic performance over three consecutive cycles. These findings demonstrate the potential of sulfur-modified palm kernel shell-derived porous carbon as an effective, reusable solid-acid catalyst for the synthesis of ethyl levulinate.

Keywords: Biofuel, Esterification, Heterogeneous Catalyst, Porous Carbon

INTRODUCTION

The world's energy demand continues to

increase, which could trigger an energy crisis. Dependence on energy derived from fossil fuels, such as coal and oil has made matters

worse by increasing carbon dioxide emissions, which have led to a general rise in global temperatures. Currently, carbon dioxide concentration continues to increase and has reached its highest level in the last 63 years (Lan *et al.*, 2025). If this is not addressed, Earth's climate change will have significant effects on humans, industry, and the world economy (Coyle and Simmons, 2014).

In the midst of the electrification fever for various modes of transportation, such as electric cars, electric motorbikes, and electric trains, heavy and long-distance modes of transportation remain resistant to electrification. This is because the energy required for a heavy truck to move per unit weight and distance is not economical enough to use electricity. The energy density of the battery and the refueling infrastructure remain major obstacles. Therefore, biodiesel is one of the solutions for heavy and long-distance transportation modes. Biodiesel produced from crude palm oil (CPO) has a fundamental weakness relative to petroleum-based diesel fuel: poor low-temperature operating capability (Joshi *et al.*, 2011; Sumatri *et al.*, 2023). The dew point (CP) and pour point (PP) of CPO-based biodiesel are 21°C and 19.7°C, making operation capability at low temperatures a serious issue that must be solved because room temperatures in the highlands can easily fall below the CP and PP of CPO-based biodiesel (Giraldo *et al.*, 2013; Verma *et al.*, 2016). Several methods are used to overcome the constraints of biodiesel operation at low temperatures, such as mixing with petroleum-based diesel fuel (Moser *et al.*, 2008), Winterization (Kerschbaum *et al.*, 2008), and the addition of additives (Giraldo *et al.*, 2013). One of the products derived from levulinic acid, namely ethyl levulinate, can be used as an additive to improve the CP and PP values of biodiesel

(Joshi *et al.*, 2011).

Levulinic acid is a compound that has a ketone group and a carboxylic acid, which can be used as a fuel additive, polymer, and resin (Dussan *et al.*, 2013) as well as raw materials for various kinds of chemical compounds such as drugs, lubricants, inks, batteries, and corrosion inhibitors (Weingarten *et al.*, 2013). No doubt this gives levulinic acid the flexibility to yield various derivative products and makes it useful for solving problems in many fields, including the energy sector.

Conventional homogeneous acid catalysts, such as sulfuric acid (H₂SO₄) and hydrochloric acid (HCl), are still widely employed for the esterification of levulinic acid because of their high catalytic activity. However, these catalysts suffer from several drawbacks, including their corrosive nature, difficulty in separating them from the reaction products, generation of hazardous acidic waste, and limited reusability, making them less compatible with the principles of green chemistry and sustainable industrial processes (Gautam *et al.*, 2022; Oppong *et al.*, 2025). Consequently, recent studies have increasingly focused on developing heterogeneous catalysts as a more environmentally friendly and sustainable alternative.

The synthesis of ethyl levulinate can be carried out using various types of catalysts such as silica-based catalysts (Ristiana *et al.*, 2022; Yang and Tang, 2019), heteropolyacids (Ramli *et al.*, 2017), zeolites (Hauli *et al.*, 2024; Nandiwale *et al.*, 2014), ion-exchange resins such as Amberlyst-15 (Grammenou *et al.*, 2025), metal salts (Martins *et al.*, 2018), and modified hydrochar (Gautam *et al.*, 2022). Heterogeneous catalysts commonly used in esterification processes, such as ZnO (Singh *et al.*, 2013), Fe_xO_y (Suzuta *et al.*, 2012), and CuO (Ong *et al.*, 2014), can also be used.

Recent studies have also demonstrated the potential of biomass-derived sulfonated carbon catalysts for ethyl levulinate production owing to their high acidity, reusability, and sustainable feedstocks (Suminar *et al.*, 2024).

Despite these advances, there are still few studies on the use of porous carbon as a solid-acid catalyst for the synthesis of ethyl levulinate, particularly for catalysts derived from renewable biomass. Porous carbon can be produced from abundant biomass waste (Ariyanto *et al.*, 2020) or synthetic polymer (Mutia *et al.*, 2022). Among biomass precursors, palm kernel shell is an attractive carbon source because of its abundance as an agricultural by-product (Ariyanto *et al.*, 2020).

This research explores the sulfur modification of biomass-derived porous carbon via sulfuric acid sulfonation and the use of a solid-acid catalyst to synthesize ethyl levulinate from levulinic acid. The novelty of this study lies in evaluating the effects of sulfonation conditions on the physicochemical properties, acid density, catalytic performance, and reaction kinetics of biomass-derived porous carbon, a sustainable solid acid catalyst.

Porosity, surface, and thermal characteristics of heterogeneous catalysts were evaluated, along with the number of active sites generated by the modification process. The performance of the catalyst in the esterification process was investigated, along with data fitting to obtain kinetic parameters, which provide essential information for reactor design, process optimization, and the scale-up of ethyl levulinate production. Furthermore, this study contributes to the development of sustainable heterogeneous catalysts derived from renewable biomass resources. It supports the efficient production of ethyl

levulinate, a promising biodiesel additive with improved environmental compatibility.

MATERIALS AND METHODS

Materials

The main materials used in this study were biochar from palm kernel shells (PKS) provided by PT Jambi Nusantara Energi, Indonesia; sulfuric acid (98% purity, Merck); absolute ethanol (99.99% purity, Merck); and levulinic acid (99% purity, Merck).

Production of Palm Kernel Shell-Derived Porous Carbon

Porous carbon was synthesized from biochar of palm kernel shells, according to a previous method provided in the literature (Prasetyo *et al.*, 2020). Briefly, the biochar was placed in the isothermal zone of a tube furnace (OTF-1200X, MTI, USA). The system was evacuated to remove oxygen, then purged with nitrogen (99% purity) at a flow rate of 100 mL min⁻¹. The furnace was heated from room temperature to 800 °C at a heating rate of 2 °C min⁻¹ and maintained at this temperature for 2 h. Steam was introduced into the furnace when the temperature reached 600 °C to activate the carbon. The resulting porous carbon, designated as C-PKS, was obtained with a yield of approximately 40% based on the initial biochar mass.

Synthesis of Sulfur Modified Palm Kernel Shell-Derived Porous Carbon

Porous carbon was then sulfonated using sulfuric acid at concentrations of 10, 30, and 50 wt%. At the same time, all other sulfonation conditions, including the carbon-to-acid ratio (1:6 w/v), reaction temperature (90 °C), reaction time (2 h), and catalyst particle size (0.300–0.355 mm), were kept

constant. After the sulfonation process, the porous carbon was thoroughly washed with distilled water using vacuum filtration until the filtrate reached a neutral pH. The carbon was then dried in an oven at 60 °C overnight. C-PKS-10-S, C-PKS-30-S and C-PKS-50-S represent C-PKS sulfonated with 10, 30, and 50% sulfuric acid, respectively.

Material Characterizations

The carbon surface was characterized qualitatively and quantitatively. Qualitative analysis was carried out using the Scanning Electron Microscopy (SEM) JSM-6510 LA (JEOL, Japan) to determine the morphology of the carbon surface. Energy-dispersive X-ray spectroscopy (EDX) was used concurrently with SEM to analyze elements on the carbon surface. Pore characteristics were determined by the nitrogen sorption analysis method at 77 K with Quantachrome NOVA 2000. The surface area was determined by the Multipoint Brunauer-Emmett-Teller (BET) method with constant physical parameters used to evaluate the carbon surface area. The surface acidity of porous carbon was analyzed using Boehm titration. Thermal stability was examined using a thermogravimetric analyzer (STA PT1000, Linseis) at 30–700 °C at 5 °C/min under nitrogen.

Esterification Reaction

Esterification of levulinic acid was carried out using a reaction flask equipped with an oil bath and a magnetic stirrer. Ethanol and levulinic acid were first mixed in a beaker at a molar ratio of 5:1 to obtain a total reaction volume of 40 mL, then heated at 70 °C with a stirring speed of 300 rpm. A catalyst loading of 5% (w/v) was employed for all catalytic experiments. The first esterification was carried out using levulinic acid and ethanol

without a catalyst as a control for the subsequent experiments. During the reaction, 50 µL aliquots were withdrawn using a micropipette at predetermined time intervals selected to adequately capture the reaction profile, with a total of ten samples collected throughout the 120 h reaction period. The cumulative sampled volume (0.5 mL) corresponded to approximately 1.25% of the initial reaction volume, thereby minimizing any potential influence of sample withdrawal on the overall reaction performance. The experiment was subsequently repeated using C-PKS-10-S, C-PKS-30-S, and C-PKS-50-S catalysts prepared using different sulfuric acid concentrations (10, 30, and 50 wt%), while all esterification conditions were kept identical. Catalyst repetition experiments were carried out using the C-PKS-10-S catalyst. Samples from the series of experiments were then analyzed by acid-base titration using a standardized NaOH solution and a phenolphthalein indicator to determine the levulinic acid residue. The levulinic acid content of the samples was then processed and compared for analysis. Details of the esterification process can be found in the literature (Pramudikto, 2023).

Kinetic Modeling

The esterification of levulinic acid with ethanol over the sulfonated porous carbon catalyst was described using a reversible dual-site Langmuir–Hinshelwood–Hougen–Watson (LHHW) model, as previously reported for heterogeneous acid-catalyzed esterification reactions (Nandiwale *et al.*, 2014). The LHHW mechanism assumes that both levulinic acid and ethanol are first adsorbed onto the catalyst surface before undergoing the surface reaction. This approach is widely applied to heterogeneous solid acid catalysts with abundant acidic sites

and high surface area, in which the adsorption of both reactants significantly influences the overall reaction rate (Gallego-Villada *et al.*, 2024; Yadav and Yadav, 2014). Therefore, the LHHW model was selected to describe the reaction kinetics over the sulfonated porous carbon catalysts investigated in this study. The reaction rate is expressed as:

$$\frac{dX_{LA}}{dt} = k_1 \left(k_2 (1 - X_{LA}) (C_{Et_0} - C_{LA_0} X_{LA}) - \frac{C_{LA_0} X_{LA}^2}{K_r} \right) \quad (1)$$

where k_1 is the reaction rate constant, k_2 is the adsorption equilibrium constant, and K_r is the reaction equilibrium constant. Under identical operating conditions, k_2 and K_r were assumed to remain constant for all sulfur-modified carbon catalysts, whereas k_1 was determined individually for each catalyst by fitting the experimental levulinic acid conversion data.

RESULTS AND DISCUSSION

Properties of Sulfur Modified Palm Kernel Shell-Derived Porous Carbon

To evaluate the pore structure of porous carbon, sorption analysis was performed, and the isotherm was plotted as shown in Figure 1a. In general, all porous carbon from palm kernel shells exhibits type I adsorption, with a slight deviation towards type IIIa and a little hysteresis (Thommes *et al.*, 2015). A striking difference is evident in the heights of the adsorption and desorption graphs for C-PKS and its sulfonated derivatives. Increasing the concentration of sulfuric acid during sulfonation decreases the nitrogen adsorption volume.

Decreasing the adsorption volume at low pressure ($P/P_0 < 0.1$) for all sulfonated

carbons indicates that the reaction between the sulfuric acid solution and the porous carbon reduces the microporous fraction of the carbon. As the concentration of sulfuric acid increases, the carbon micropores get smaller. This can be seen in the decrease in the adsorption value at low pressure.

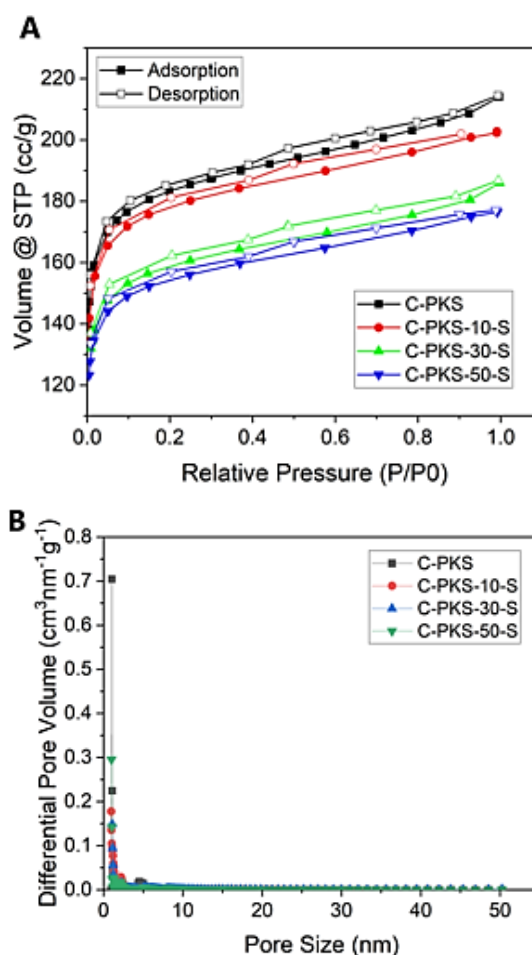


Fig. 1: (a) N₂-sorption isotherm and (b) pore size distribution of C-PKS, C-PKS-10S, C-PKS-30S and C-PKS-50S

The reduction in nitrogen adsorption volume after sulfonation has also been reported in previous studies. It is commonly attributed to oxidation of the carbon surface by concentrated sulfuric acid, and to the introduction of sulfur-containing acidic functional groups (Hasse *et al.*, 2015; Mateo *et al.*, 2020). Sulfonation modifies the physicochemical properties of the porous

carbon, leading to a decrease in the accessible surface area and nitrogen adsorption volume while simultaneously increasing the density of acidic active sites available for catalytic reactions.

Figure 1b shows C-PKS pore distribution curves. Pristine and sulfur-modified porous carbon still exhibit significant micropores. This is consistent with the adsorption and desorption graphs, which show high adsorption at low pressure, corresponding to Type I adsorption dominated by micropores. Some mesopore peaks appear for all porous carbons in the 2-10 range. Therefore, using palm kernel shells as the raw material, a combination of micro- and mesopores is observed, consistent with the findings of Prasetyo *et al.* (2020).

Table 1 compiles the pore structure parameters. The specific surface area is between 588 and 710 m²/g, while the pore volume is in the range of 0.27-0.33 cm³/g. Despite the observed decrease in specific surface area and total pore volume with increasing sulfuric acid concentration, it is noteworthy that the mean pore size and overall porosity appear quite similar between the pristine C-PKS material and its sulfonated derivatives. This suggests that, while sulfonation modifies the pore structure through surface oxidation and the incorporation of sulfur-containing functional

groups, the overall porous carbon framework remains largely preserved, as reflected by the relatively unchanged mean pore size.

Figure 2 displays SEM images of pristine and sulfonated carbon. The differences among sulfonated carbon samples are also evident in SEM images, supporting the hypothesis regarding porosity development and morphological changes. At higher acid concentrations, a cleaner surface is seen. Furthermore, it is shown that with increasing acid concentration, void openings of porous carbon are seen. This highlights that the acid oxidator plays a role in void development and surface morphologies.

Figure 3a shows the thermal characteristics of C-PKS-10-S, C-PKS-30-S, and C-PKS-50-S evaluated using thermogravimetric analysis. Mass reduction in the temperature range of 30 - 150 °C occurs due to the loss of water and moisture adsorbed on the catalyst. The mass reduction in mass in the range of 220 – 600 °C can be attributed to the loss of sulfo groups from the carbon surface (Li *et al.*, 2019). The mass reduction in the range of 600 – 700 °C can be attributed to further degradation of the porous carbon. These results indicate that the sulfonated porous carbon catalysts remain thermally stable at the esterification reaction temperature (70 °C) and confirm the successful incorporation of thermally

Table 1. Pore textural parameter of porous carbon and sulfonated materials

Material	S _{BET} [m ² /g] ^a	V _{total} [cc/g] ^b	V _{meso} [cc/g] ^c	V _{micro} [cc/g] ^c	Mean Pore Size [nm] ^d
C-PKS	708.18	0.33	0.083	0.250	1.85
C-PKS-10 S	678.77	0.31	0.040	0.272	1.84
C-PKS-30 S	604.41	0.29	0.045	0.242	1.90
C-PKS-50 S	588.78	0.27	0.037	0.236	1.85

a) Specific surface area calculated by the Brunauer-Emmett-Teller (BET) model

b) Total pore volume determined from maximum nitrogen adsorption at 0.95 P/P₀ (V_T)

c) Mesopore area and pore volume calculated by subtracting the microporous properties obtained from the *t*-plot method

d) Mean pore size calculated by 4V/BET

decomposable sulfo-functional groups on the carbon surface.

The FTIR spectra (Figure 3b) further confirm the successful incorporation of sulfur-containing functional groups onto the carbon surface after sulfonation. Characteristic absorption bands observed at approximately 1100 cm^{-1} and 650 cm^{-1} are assigned to the S=O stretching vibration of sulfonic acid groups and the C-S stretching

vibration, respectively (Chen and Fang, 2011; Zeng et al., 2014). The presence of these characteristic bands is consistent with the formation of $-\text{SO}_3\text{H}$ groups during sulfonation, thereby supporting the increase in acid density observed after sulfonation.

The amount of acid indicates how many acid sites or acid functional groups are in the catalyst. The greater the value of the amount of catalytic acid, the more acid sites or acid

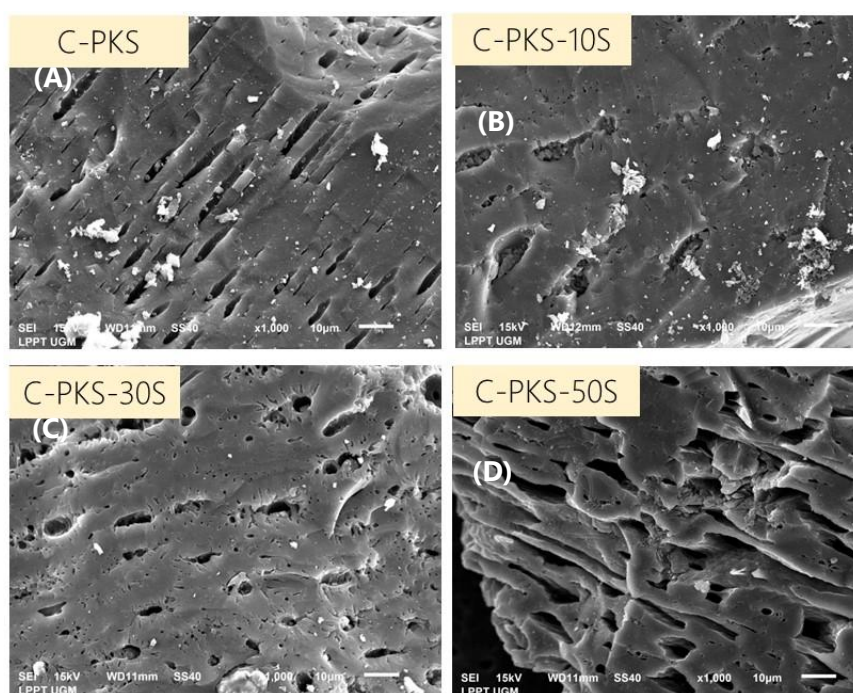


Fig. 2: SEM images of (a) C-PKS, (b) C-PKS-10S, (c) C-PKS-30S and (d) C-PKS-50S

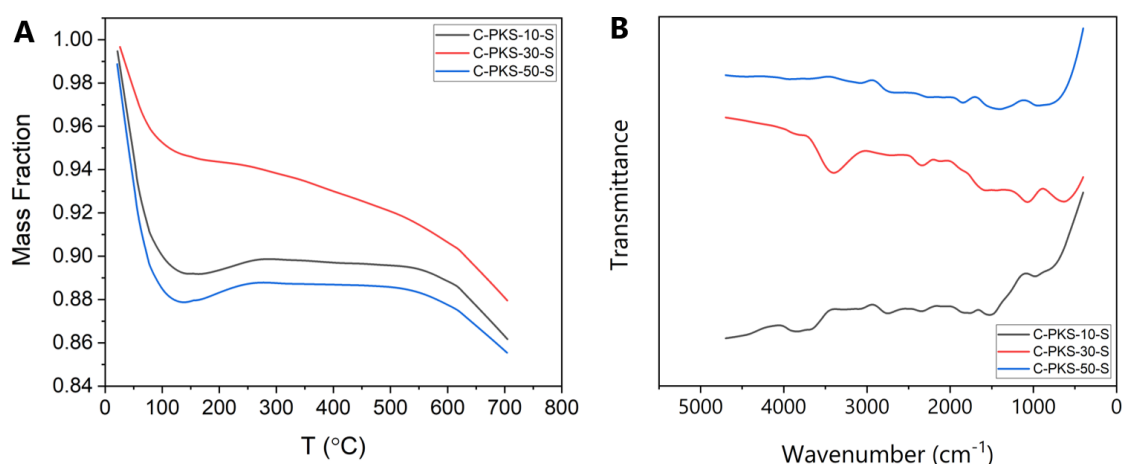


Fig. 3: (a) Remaining mass curves obtained from thermogravimetric analysis (TGA) and (b) FTIR spectra of sulfur-modified porous carbon catalysts (C-PKS-10-S, C-PKS-30-S, and C-PKS-50-S).

functional groups available to carry out the esterification reaction. This, of course, will positively impact the overall reaction kinetics. The amount of carbon catalyst acid is presented in Table 2. The slightly negative acid density obtained for pristine C-PKS ($-0.01 \text{ mmol g}^{-1}$) is attributed to experimental uncertainty associated with the Boehm titration method. It should be interpreted as indicating the absence of measurable acidic functional groups rather than an actual negative acid density. For the sulfonated samples, increasing the sulfuric acid concentration increased the acid density. Increasing the concentration of sulfuric acid from 10 to 30% also increased acid density from 0.10 mmol/g to 0.37 mmol/g. But when the sulfuric acid concentration increased from 30 to 50%, the amount of acid is more or less equal, indicating that a maximum amount of acid is achieved in the sulfonation condition. The increase in acid density following sulfonation is consistent with the successful incorporation of $-\text{SO}_3\text{H}$ groups onto the carbon surface, which serve as Brønsted acid sites that catalyze esterification (Mateo *et al.*, 2020; Zeng *et al.*, 2016).

Table 2. The amount of acid in porous carbon and sulfonated materials

Material	Acid density (mmol/g)
C-PKS	-0.01
C-PKS-10-S	0.10
C-PKS-30-S	0.37
C-PKS-50-S	0.36

Catalytic Performance of Sulfur-Modified Palm Kernel Shell-Derived Porous Carbon

To evaluate the efficacy of the synthesized catalyst, an esterification reaction was carried out. The first reaction was carried out without a catalyst, and using 5% sulfuric acid as the

reference. After that, the reactions were carried out using sulfonated porous carbon at different sulfuric acid concentrations, i.e., C-PKS-10-S, C-PKS-30-S, and C-PKS-50-S. The conversion time results for the five reaction types are plotted and compared in Figure 4a. The results showed that converting sulfuric acid to ethyl levulinate via esterification with different catalysts yields varying products. The highest conversion was obtained by using sulfuric acid as a homogeneous catalyst. This high conversion is due to the homogeneous catalytic reaction that occurs directly, without the diffusion and adsorption of reactants on heterogeneous catalysts, which are slower. The use of a sulfonated carbon catalyst gives better results than a reaction without a catalyst. This conversion value is certainly lower than that obtained with a homogeneous catalyst, but it offers separation advantages later. Based on conversion after 120 hours, the order of conversion performance of sulfonated carbons was C-PKS-30-S (ca. 73%), C-PKS-10-S (ca. 65%), and C-PKS-50-S (64%).

Although sulfonation reduced the specific surface area and total pore volume of the porous carbon (Table 1), catalytic performance was not governed by surface area alone. Pristine C-PKS exhibited the highest specific surface area but negligible acid density (Table 2), indicating the absence of sufficient Brønsted acidic sites for catalyzing the esterification reaction. In contrast, C-PKS-30-S exhibited the highest acid density (0.37 mmol g^{-1}), resulting in the highest levulinic acid conversion despite its lower specific surface area. Increasing the sulfuric acid concentration from 30 to 50% did not further increase the acid density. At the same time, the specific surface area and pore volume continued to decrease, resulting in a slight decline in catalytic performance.

These results suggest that the catalytic activity of the sulfonated porous carbon is governed by an optimum balance between the density of Brønsted acidic sites and the preservation of the porous structure rather than by specific surface area alone, which is consistent with recent findings reported by Hassan *et al.* (2025).

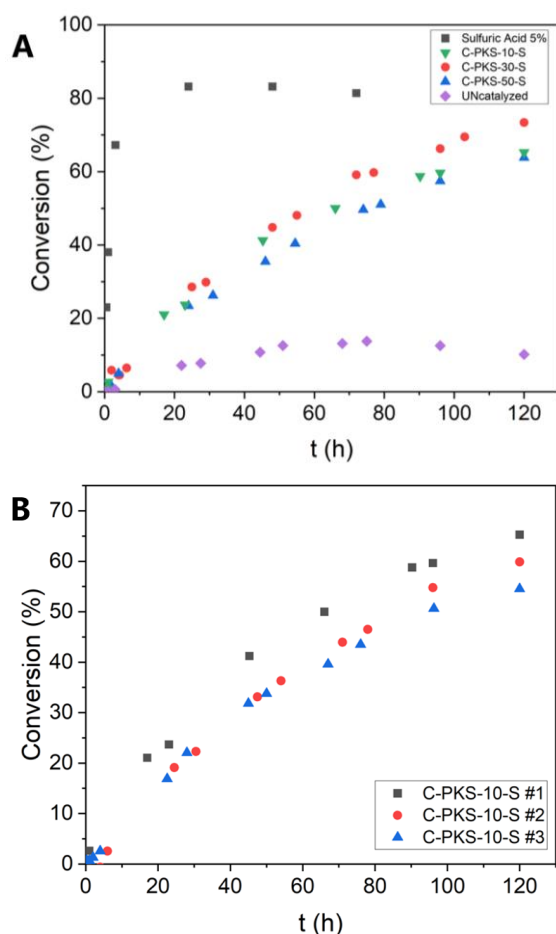


Fig. 4: (a) Conversion of levulinic acid vs time for uncatalyzed, using sulfuric acid as a homogeneous catalyst, and different sulfonated materials, and (b) catalyst repetition experiment for C-PKS-10S.

Furthermore, the levulinic acid esterification reaction was repeated using the previously used catalyst. To repeat this reaction, the spent C-PKS-10-S was decanted and reused by adding reactants at the same volume and molar ratio as in the previous

reaction. The reaction was repeated two times. Figure 4b shows the conversion of levulinic acid using the C-PKS-10-S catalyst for 3 reactions. In general, the conversion of levulinic acid for each reaction continues to decrease. At first, the conversion of levulinic acid was ca. 65%. In the first repetition of the reaction, the conversion reached ca. 60%. In the final repetition of the reaction, the conversion reached 56%.

The decrease in catalytic performance may be attributed to the partial loss of sulfonic acid groups from the carbon surface during the reaction, as reported in previous studies (Guo *et al.*, 2020; Li *et al.*, 2019). Another possible explanation is the adsorption of reaction by-products on the catalyst surface, which may block active sites and reduce their availability for subsequent reaction cycles. Although there was a decrease in levulinic acid conversion, the results indicate that the catalyst can be easily reused with a moderate decrease in performance (14% reduction over three cycles). Further characterization of the spent catalyst will be required in future work to distinguish between these possible deactivation mechanisms.

Based on Figure 5 and Table 3, the proposed reaction kinetics model is consistent with all data obtained during the research using sulfonated carbon catalysts. The low SSE values presented in Table 3 indicate good agreement between the experimental and modeled levulinic acid conversion, demonstrating the reliability of the proposed kinetic model. Based on the proposed reaction kinetics model, k_2 was set to 0.075 and K_r to 16.35. The highest kinetic constant is observed for C-PKS-30-S (ca. 0.014 mL/mmol/h). With the obtained kinetic parameters, reactor design and process scale-up can be performed more reliably.

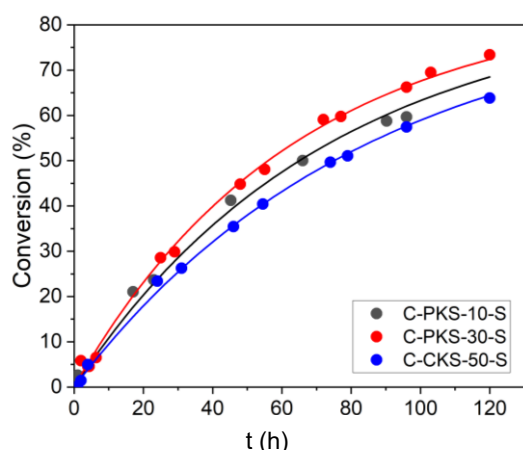


Fig. 5: Comparison of experimental and modeled conversion of levulinic acid over sulfur-modified porous carbon catalysts.

Table 3. Kinetic parameters for the esterification reaction over sulfur-modified porous carbon catalysts

Catalyst	k_1 [$\frac{\text{mL}}{\text{mmol}\cdot\text{h}}$]	k_2	K_r	SSE
C-PKS-10-S	0.012	0.075	16.35	2.73×10^{-3}
C-PKS-30-S	0.014	0.075	16.35	2.18×10^{-3}
C-PKS-50-S	0.011	0.075	16.35	9.07×10^{-4}

CONCLUSIONS

The study demonstrates that the sulfuric acid concentration used in the sulfonation process is critical to the acid density and catalytic performance of biomass-derived porous carbon. Although increasing the sulfuric acid concentration reduced the specific surface area and total pore volume, the overall porous framework was largely preserved. Sulfonation with 30 wt% sulfuric acid produced the highest acid density (0.37 mmol g^{-1}) and exhibited the highest catalytic activity for levulinic acid esterification, with a reaction rate constant of approximately $0.014 \text{ mL mmol}^{-1} \text{ h}^{-1}$. These results indicate that catalytic performance is governed by an optimum balance between the density of

Brønsted acidic sites and the preservation of the porous structure rather than by specific surface area alone. Furthermore, the sulfonated porous carbon catalyst demonstrated good reusability, exhibiting only a moderate decline in catalytic performance after three reaction cycles. Future studies should investigate optimizing sulfonation conditions and the catalyst's long-term stability to improve acid-site stability and catalytic durability further.

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AUTHORSHIP CONTRIBUTION

Dimas Agung Pramudikto: data collection, analysis, data evaluation, and writing - original draft. Muhammad Nurstia Dimas: data evaluation. Daffa Dewa Saputra: data evaluation. Rochim Bakti Cahyono: conceptual, supervision. Ahmad Tawfiequrrahman Yuliansyah: conceptual, supervision, writing - review & editing. Imam Prasetyo: conceptual, supervision. Teguh Ariyanto: conceptualization, resources, supervision, writing - review & editing.

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