

Production of Biodiesel From Cashew Nut Shell Liquid Using Cashew Nut Shell Derived Bio-char Catalyst

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Abstract

Biodiesel has recently received widespread attention as an essential source of renewable and environmentally friendly energy due to its ease of production and clean burning. Cashew nutshell is a biomass waste readily available in India. This work studies the production of *fatty acid methyl ester (FAME)* from the *cashew nut shell liquid (CNSL)* using sulfonated cashew nutshell biochar catalyst by transesterification reaction. Catalyst efficiency is compared with a conventional catalyst for biodiesel production. Characterization of the catalyst was done using FTIR, TGA, elemental analysis, and BET. Transesterification studies were carried out using KOH and the biochar catalyst. These studies inferred that the highest conversion of CNSL to FAME is achieved by using the conventional catalyst KOH (94.2% yield) and process parameters of 65⁰C reaction temperature, 1hr reaction time, 18:1 methanol to oil ratio, and 5 w/w % catalyst weight. The highest conversion achieved using the biochar catalyst was 43.4% at optimum process parameters. The study revealed the feasibility of producing FAME from waste biomass, which lowers production costs and benefits environmental sustainability.

1. Introduction

The world's population is increasing, and the developing world's economies are expanding. Demand for fuel is always on the rise (Guo 2013). The major problem of fossil fuels is higher carbon emission and depletion of oil reserves (Ishola et al. 2020). The primary drivers of alternative fuels are sustainable development and environmental preservation (Justin Abraham Baby et al., 2021). Because of its superior performance and benefits of renewable, clean, degradable, pollution-free, non-toxic, biodiesel is often regarded as the most viable alternative energy source to petroleum diesel (Gohain et al. 2017; Zhang et al. 2020). Fatty acid methyl ester is another name of biodiesel. It can be made by transesterifying renewable sources such as vegetable oil, animal fats with short-chain alcohol in the presence of a catalyst (Bastos et al. 2020; Guo et al. 2020).

Two different catalysts used to synthesize biodiesel are homogeneous and heterogeneous catalysts. homogeneous catalysts like sulphuric acid, sodium, and potassium hydroxides are highly active. However, their industrial applications are limited due to the side reaction of saponification, equipment corrosion, and separation complexity (Qu et al. 2020). heterogeneous catalysts have attracted widespread attention due to their advantages. non-toxic to the equipment (Chen et al. 2020), easily separable from the biodiesel product, which improves biodiesel quality and reduces post-treatment cost (Naik and Meivelu 2020). heterogeneous base catalyst is more efficient than heterogeneous acid catalyst as they catalyze the reaction 4000 times faster than heterogeneous acid catalyst (Sahani et al. 2020). the major drawback of heterogeneous catalysts is that it requires high temperature and pressure for acidic heterogeneous catalysts, low acid value feedstock for basic catalysts, and high cost for immobilized enzymatic catalysts (Khandan and Saffarzadeh-Matin 2020).

The main drawback of using edible oils as biodiesel feedstock is their high cost, dependence on food price (Pikula et al. 2020). in the present study, cashew nut seed shell is used for the production of

biodiesel. India is the second-largest producer, processor, and exporter of cashews in the world (Deepanraj et al., 2021). Cashew cultivation now covers a total area of 0.70 million hectares of land, producing over 0.40 million M.T. of raw cashew nuts annually (Padmanaban et al. 2014). The cashew nut is separated from the fruit, washed, sun-dried, and roasted to extract the cashew nut and separate the cashew kernel. The nut has a shell of about 1/8th inch thickness inside, which is a soft honeycomb structure. The extractable oil is called cashew nut shell liquid and has numerous applications in the polymer industry such as friction lining, paints, and varnishes, rubber compounding resins, cashew cement, biocomposite, the monomer for polymers, etc. (Lubi and Thachil 2000; Smith Jr et al. 2003; Subbarao et al. 2011). Cashew Nut Shell Liquid (CNSL) is a useful cashew industry byproduct. The cashew nutshell contains 20% CNSL. The oil can be extracted by roasting the cashew kernel or by using an oil extraction method such as solvent extraction. Untreated CNSL is a dark reddish-brown liquid that is viscous and vesicant. Despite the fact that CNSL has a wide range of applications in the polymer area, (Taiwo 2015), few studies have been conducted on the feasibility of the oil as a feedstock for biodiesel preparation. Here focus is two fold, using cashewnut shell biomass which is an agriculture waste as an easily available biochar and using CSNL which is a cheap, non edible natural oil as a biodiesel source. Thus the entire cost of production can be significantly reduced.

2. Experimental

2.1. Materials

Cashew nutshell biomass was collected from a Shelling plant in Tamil Nadu. Cashew nut shell liquid (CNSL) was extracted from the cashew nutshell using the solvent extraction method. Chemicals used for the extraction and catalyst preparation are Sodium hydroxide (Emplura Merck Specialties Private Ltd.), oxalic acid (spectram reagent & Chemicals Pvt Ltd.), hydrochloric acid (Himedia Laboratories Private Ltd.), Phenolphthalein (Nice Chemicals Private Ltd.), Hexane (Sisco Research Laboratories Private Ltd.), Ethanol (Chong Yu Hitech Chemicals China), Potassium Hydroxide (Himedia Laboratories Private Ltd.), Sulphuric acid (Merck Life Sciences Private Ltd.). Distilled water is used for dilution of chemicals and washing of glass apparatus.

2.2 CNSL extraction from Cashew Nut Shell

55gm of washed, dried, and crushed cashew nutshell was charged into the thimble of the Soxhlet extractor. 250mL of n-Hexane was used as a solvent for extraction. The apparatus was set for 4 hours to ensure complete extraction of solvent. The extracted biomass was dried at 75°C in a hot air oven. Boiling point of n-hexane is 68°C. This method was repeated 4 times with fresh biomass to obtain ~180gms of biomass. The dried biomass was further crushed and separated using sieve analysis. CNSL is extracted from the raffinate by simple distillation

The hexane- CNSL mixture is collected into a round bottom flask placed on a heating mantle. The round bottom flask is connected to a spiral condenser using a right-angled adapter. A collecting conical flask is

placed at the receiving end of the condenser to collect the distillate (hexane). Cooling water is supplied to the spiral condenser. The mixture is heated to 75°C. Boiling point of n-hexane is 68°C; hence the hexane distills and is collected in the conical flask. The hexane-free CNSL is poured into an air tight glass vessel for further use (Smith Jr et al. 2003; Subbarao et al. 2011; Anang et al. 2019)

2.3 Synthesis of catalyst

The crushed CNS was weighed (20gm) and charged into a muffle furnace under constant Nitrogen supply for duration of the reaction time. After the reaction time, the char was removed into an air-tight container. 10gm of biochar was dried in a hot air oven at 105°C for 10 minutes. The biochar was then placed into a stoppered conical flask. 100mL of concentrated H₂SO₄ was carefully added into the conical flask and closed using the stopper. The flask is gently shaken to ensure proper mixing of biochar and acid. The flask with its contents was placed into a muffle furnace preheated to the required temperature. Activation is allowed for 1 hour, after which the flask is removed and allowed to cool at room temperature. The biochar-acid mixture is poured into centrifuge tubes. The mixture is separated in a centrifuge machine at 3000 RPM. The liquid layers are removed, and the remaining catalyst is diluted with hot distilled water and shaken. The mixture is again set to separate in the centrifuge machine. This process was repeated 4 times. Finally, the catalyst was separated from the water through the process of filtration. The catalyst was allowed to dry in a hot air oven at 105°C for 1 hour and was put into an airtight vessel to prevent moisture absorption (Yu et al. 2011; Kastner et al. 2012; Chellappan et al. 2018; Yasodhara et al. 2021).

2.4 Catalyst Characterization

The physical and chemical characterization of prepared catalyst is evaluated using different techniques like BET method used to study the surface area, pore volume and pore size of catalyst. Hitachi TGA Thermogravimetric analyzer was used to investigate thermochemical degradation behavior. X-ray powdered diffraction (XRD) was performed to find 2θ angle by scanning 4-80°, FTIR (JASCO-4100) and Elemental analyzer.

2.5 Synthesis of Biodiesel

2.5.1. Esterification Reaction

Esterification of CNSL was conducted at atmospheric pressure in a batch reactor consisting of a 250 ML two neck round-bottomed flask with a spiral refluxing condenser, thermometer, and a hot plate with a magnetic stirrer. In a typical experiment, a specified amount of oil was preheated to 105°C for 15 minutes for moisture removal. During this process, a specified amount of methanol and catalyst were mixed thoroughly. The temperature of the CNSL was brought down to the required temperature and the methanol-catalyst mixture was poured and the condenser was set. The mixture was refluxed at the desired temperature for a specified amount of time with simultaneous stirring at 400 RPM. The mixture was reheated to 70°C for removing excess methanol. The Acid Value of the esterified oil was determined using NaOH. The calculation for conversion is given below (Marchetti and Errazu 2008; Guo et al. 2021)

$$\text{FFA Conversion \%} = \frac{\text{FFA}_i - \text{FFA}_f}{\text{FFA}_i}$$

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Where FFA_i is the initial Acid Value and

FFA_f is the final Acid Value

Approximate FFA % = Acid Value/1.99

The optimum process parameters were taken for the comparative study of the conventional acid catalyst and the prepared catalyst.

2.5.2. Transesterification Reaction

After reducing the acid value of CNSL through the process of esterification, Biodiesel was produced by transesterification of the parent oil using a conventional base catalyst. The optimum process parameters was adopted in the comparative study of the catalyst as a catalyst for transesterification.

A specified amount of methanol and catalyst were mixed together and poured into a two neck round bottom flask containing the esterified CNSL. A thermometer was placed to measure and control the reaction temperature. The round bottom was set with a spiral reflux condenser onto a heated magnetic stirrer for the duration of the reaction time. After completion of the reaction, the glycerin layer was allowed to separate from the FAME layer in a separating funnel overnight. The glycerin layer was removed and discarded. The FAME layer was heated to 70°C to remove any excess methanol and then thoroughly washed in heated distilled water to remove impurities like soap, catalyst, and glycerol. The biodiesel was heated to above 100°C to remove any moisture traces and stored in an air-tight container. The yield of Biodiesel was determined by the equation (Khan et al. 2020; Munawar and Manurung 2020; Yusuff and Adesina 2020):

$$\text{Biodieselyield (wt \%)} = \frac{\text{Weight of purified Biodiesel}}{\text{Weight of raw oil used}} \times 100$$

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3. Result And Discussion

3.1 Characterization of catalyst

Elemental analysis of the catalyst was conducted and compared with that of the precursor biochar. The results are tabulated in Table 1. From the table, we can infer that as the reaction temperature increases, quantity of sulphur present in the catalyst reduced. There is also a decrease in carbon and hydrogen implying the release of C-H gas. The higher quantities of S% is a desired result of the activation. We can infer that acid groups have adhered to the surface of the catalyst (Chellappan et al. 2018).

Table 1
Elemental Analysis of Biochar and Catalysts

Sl. No	Sample Name	N%	C%	S%	H%	O%	H/C	O/C
1.	Biochar 1hr	1.22	62.41	1.07	3.81	31.49	0.061	0.504
2.	Catalyst 90°C	0.90	51.15	6.24	3.38	38.33	0.066	0.749
3.	Catalyst 200°C	0.71	42.74	1.13	0.31	55.11	0.007	1.289

Lower S% content in the catalyst activated at 200°C could be explained due to the fluctuating temperature in the furnace and improper mixing of the acid during activation procedure(Kastner et al. 2012).

Table 2
Functional groups present in biochar-catalyst

Wavenumber (cm ⁻¹)	Functional Group
572.1	Aromatic CH Bending
1019.4	-SO ₂ - symmetric stretching
1131.2	-SO ₃ H- asymmetric stretching
1578.5	Carboxylic Acid C=O symmetric Stretch

TGA analysis of the catalysts were performed in the presence of N₂. The weight % vs increasing temperature of each catalyst was plotted for comparison as shown in Figure 1. The initial 10-15% loss of weight is attributed to the free moisture and water desorption. After which there is slight plateau between 100-250°C thereafter a slow and steady weight loss occurs. Overall the samples lost 49% and 46% of their overall mass for catalyst prepared at 90°C and 200°C respectively.

FTIR spectroscopy was conducted on samples of both catalysts. The spectrum was plotted for comparison as shown in Figure 2 Comparison of the plots infers that no additional functional groups have been found in the catalyst activated at 200°C. The functional groups found in t(Lim et al. 2020; Wang et al. 2020; Satapute et al.)he catalyst are provided Table 2.

The catalysts exhibited the typical bands of carbonyl groups (C=O, at 1578cm⁻¹) and characteristic peaks of incompletely carbonized materials, near 572cm⁻¹ attributable to aromatic ring modes. The appearance of additional bands at 1094cm⁻¹ (SO₂ stretching) and 1131 cm⁻¹ (stretching in -SO₃H-) in the FTIR spectra of the sulfonated carbons were consistent with the presence of -SO₃H- groups. The higher peak intensities of -SO₂- and -SO₃H- correspond to the activation yield of the catalyst(Lim et al. 2020; Wang et al. 2020; Satapute et al.).

XRD analysis was conducted on both the catalyst. The graph of XRD confirms that both catalyst is amorphous in nature devoid of any crystalline compound or group present on the catalyst surface. The

XRD plot is shown in Figure 3 and 4 for catalyst produced at 90°C and 200°C.

The catalyst shows diffraction peaks at 2θ range of 15-30° region, which indicates that of an amorphous carbon structure with randomly oriented aromatic carbon sheets(Wang et al. 2017).

Through these characterization techniques, it was determined that the catalyst produced at 90°C contained the ideal functional groups and properties for biodiesel production from CNSL.

BET analysis was conducted on the catalyst and the surface area was found to be 35.429 m²/g.

3.2. Esterification Parameter Studies

3.2.1. Influence of Catalyst Weight and Reaction time

Esterification was conducted in a round bottom flask heated on a magnetic stirrer with the use of spiral condenser for reflux. The methanol to oil ratio, reaction temperature and stirring rate were kept constant at 25:1, 65°C and 600RPM respectively. The reaction time was incremented every 60mins. The catalyst weight utilized for the esterification were 15w/w%, 16w/w%, 17w/w%, 18w/w%, 19w/w%, 20w/w% and 25w/w%. The graph of the FFA conversion % with respect to reaction time is plotted in Figure 5. From the graph we can infer that for lower catalyst weight (15w/w %) there is a sharper increase in percentage conversion of FFA with initial conversion (at 60mins) of 18.6% and final conversion (at 240mins) of ~40%. It is also observed that for increased catalyst weight the initial and final conversion of FFA increased. For higher catalyst weight, though conversion of FFA, the rate of conversion is lower when compared to using low catalyst weight. Highest conversion was achieved at 240mins of catalyst weight of 25w/w % of 80.35%.

Using the optimum parameters for esterification while keeping methanol to oil, reaction temperature and stirring rate constant, esterification was carried out for the two types of catalyst i.e. homogeneous and heterogeneous catalyst. Esterification reaction was performed with reaction temperature at 65°C and rotational Speed was 600RPM. The homogeneous (H₂SO₄) and heterogeneous (biochar catalyst) was taken are 25w/w%. Methanol to oil ratio was kept constant at 30:1

The graph of the comparison study is shown in Figure 6. From the graph we can infer that the effectiveness of the biochar-catalyst is lesser than that of the conventional catalyst H₂SO₄. The highest FFA conversion using biochar catalyst was achieved at 240mins with 74.57% conversion of FFA present in CNSL. It must be noted that longer the reaction time for esterification, the higher the conversion % of FFA(Lim et al. 2020).

3.2.2. Influence of Methanol to Oil ratio and Reaction Time

Esterification was conducted in a round bottom flask heated on a magnetic stirrer with the use of spiral condenser for reflux. The catalyst weight, reaction temperature and stirring rate were kept constant at 20:1, 65°C and 600RPM respectively. The reaction time was incremented every 60mins. The methanol to

oil ratio utilized for the esterification were 10:1, 14:1, 18:1, 22:1, 26:1, 30:1, 34:1. The graph of the FFA conversion % with respect to reaction time is plotted in Figure 7.

From Figure 7, it can be observed that larger the ratio of methanol to oil, results in higher FFA conversion, therefore higher amounts of methanol will be required to cause significant conversion of FFA. Higher FFA conversion was achieved at 89.3% for 240mins reaction time and for methanol to oil ratio of 30:1.

Whereas when 34:1 methanol to oil was used there was lesser conversion of FFA. This can be explained using Le Chatlier's principle, where the increase in the reactant (methanol: oil) causes increase product formation (biodiesel and water).

From the previous study, while keeping the catalyst weight, reaction temperature and stirring rate constant at optimum conditions i.e. 20 w/w%, 65°C and 600RPM respectively. Catalyst used here was homogenous (H_2SO_4) and heterogeneous (biochar catalyst). The methanol to oil ratio was taken as 30:1 as determined by parameter study. The graph of the comparison study is shown in Figure 8.

From the graph we can infer that the effectiveness of the biochar-catalyst is lesser than that of the conventional catalyst H_2SO_4 . The highest FFA conversion using biochar catalyst was achieved at 240mins with 77.57% conversion of FFA present in CNSL.

3.2.3. Influence of Reaction temperature and Reaction Time

To comprehend the relationship between the reaction temperature and FFA conversion %, esterification reaction was conducted keeping catalyst weight, methanol to oil ratio and stirring rate constant at 20w/w%, 30:1 and 600RPM respectively. The reaction time was incremented by 60mins. The reaction temperature was varied from 50°C to 65°C incremented by 5°C. The resulting reduction in FFA conversion % was plotted against reaction time as shown in Figure 9.

Esterification was conducted at optimum conditions of methanol to oil ratio, catalyst weight previous parameter study, with varying reaction temperature.

During esterification at 40°C, FFA conversion was very low even after reaction time of 240mins. This demonstrates the significance of reaction temperature to the FFA conversion. When the reaction temperature was increased, a higher FFA conversion was observed. Highest conversion of 88.1% was observed at 65°C for 240mins reaction time.

3.2.4. Comparison of FFA conversion using heterogeneous and homogeneous catalyst

To compare the effectiveness of biochar catalyst in the study of reaction temperature to the conversion of FFA, optimum parameter were selected for the esterification where, methanol to oil ratio, catalyst weight and stirring rate were kept constant at 30:1, 20 w/w% and 600RPM respectively. The reaction

temperature was kept constant at 65°C for esterification reaction using both catalyst. The results of FFA conversion is shown in Figure 10. The comparison study of the catalyst in the esterification study of reaction time to the FFA conversion demonstrates that the homogeneous catalyst is more effective in FFA conversion of CNSL.

Although the biochar catalyst produced provided adequate conversion of 75%. It can be inferred from the above studies that the biochar catalyst when used as an acid catalyst for the esterification of CNSL (for the reduction is FFA) was able to achieve a maximum conversion ~77% under optimum conditions. Although utilization of conventional acid catalyst of H₂SO₄ yielded higher results of ~90% conversion of FFA.

Esterification was repeated under the optimum conditions for homogeneous catalyst for the preparation of esterified oil. The esterified oil was allowed to settle in a separating funnel and the bottom by-product layer was removed. The upper layer of esterified oil was heated to 70°C to remove any excess methanol. The esterified oil was used for the transesterification study using conventional homogeneous catalyst KOH and biochar- catalyst.

3.3. Transesterification Parameter Studies

The process parameters for maximum yield of FFA conversion was repeated till ~ 1000ml of esterified oil was obtained. The esterified oil (acid value 8.59mgKOH/g) was used for the transesterification reaction using methanol in the presence of conventional homogeneous catalyst aqueous KOH and heterogeneous biochar catalyst. The parameter study of transesterification was carried out using aqueous KOH. The effectiveness of the biochar catalyst as a transesterification catalyst was compared with optimum parameters are obtained from the parameter study(Wang et al. 2020).

3.3.1. Influence of methanol: oil ratio on biodiesel production

Transesterification reaction was conducted in a two necked round bottom flask on a heated magnetic stirrer. The reaction temperature and catalyst weight were kept constant at 65°C and 1.0 w/w% respectively. The reaction was conducted for 1 hour. The methanol to oil ratio was increased four times for each study. The contents were allowed to settle in a separating funnel and the FAME layer was removed and purified. The weight of the purified biodiesel was compared to esterified CNSL to obtain yield. The results for the transesterification are available in Figure 11. The reaction yield is shown to increase steadily on the increase of alcohol ratio in the biodiesel production. It was observed that the biodiesel yield stabilized at higher ratios (as seen at 16:1 and 20:1). Maximum biodiesel yield was obtained at 20:1 ratio of 85.4%.

Table 3
Comparison of catalyst in biodiesel yield for methanol to oil study

Reaction Yield%	Catalyst
85.4	KOH Catalyst
24.9	Biochar Catalyst

Transesterification study was conducted using biochar catalyst at process parameters of 65°C reaction temperature, 1 hour reaction time, 1 w/w% of catalyst at 20:1 methanol to oil ratio. The comparison of the biodiesel yield is provided in Table 3. The yield of biodiesel using the biochar catalyst is significantly lesser when compared to the conventional catalyst.

3.3.2. Influence of catalyst weight on biodiesel production

Transesterification reaction was conducted in a two necked round bottom flask on a heated magnetic stirrer. The reaction temperature and time were kept constant at 65°C and 1 hour respectively. The methanol to oil ratio was taken at 18:1 and the catalyst weight incremented by 5 for each reaction study. The contents were allowed to settle in a separating funnel and the FAME layer was removed and purified. The weight of the purified biodiesel was compared to esterified CNSL to obtain yield. The results for the transesterification are available in Figure 12.

The biodiesel production in the very first study yield high values. Further increase of catalyst weight showed a marginal increase in biodiesel yield. The maximum yield was obtained at 5 w/w% of 94.6% biodiesel.

Transesterification study was conducted using biochar catalyst at process parameters of 65°C reaction temperature, 1 hour reaction time, 5 w/w% of catalyst at 18:1 methanol to oil ratio. The comparison of the biodiesel yield has been provided in Table 4. The yield of biodiesel using the biochar catalyst is comparably higher when increasing the catalyst weight when compared to the results obtained in Table 4.

Table 4
Comparison of catalyst in biodiesel yield for catalyst weight study

Reaction Yield%	Catalyst
93.3	KOH Catalyst
37.2	Biochar Catalyst

3.3.3. Influence of Reaction time in the study of biodiesel production

Transesterification reaction was conducted in a two necked round bottom flask on a heated magnetic stirrer. The reaction temperature, catalyst weight and methanol to oil ratio were kept constant at 65°C, 3 w/w% and 18:1 respectively. The reaction time was incremented every 30mins. The contents were allowed to settle in a separating funnel and the FAME layer was removed and purified. The weight of the purified biodiesel was compared to esterified CNSL to obtain yield. The results for the transesterification are available in Figure 13.

It can be observed from the graph that the reaction time shows the rate of transesterification is higher in the initial 60mins thereafter there is a marginal increase in biodiesel yield as the reaction time progress. Although maximum yield was obtained at 120mins of 95.1% conversion.

Transesterification study was conducted using biochar catalyst at process parameters of 65°C reaction temperature, 1 hour reaction time, 3 w/w% of catalyst at 18:1 methanol to oil ratio. The yield of biodiesel is shown Figure 13.. It can be inferred from the results that as the reaction time progress the yield of biodiesel increases slightly. It is also observed that there is a faster rate of reaction in the first 60mins of the transesterification process. There after the reaction rate reduces significantly.

From the transesterification studies it can be inferred that highest conversion of CNSL to biodiesel is achieved through the use of the conventional catalyst KOH (94.2%) and process parameters of 65°C reaction temperature, 1hr reaction time, 18:1 methanol to oil ratio and 5 w/w% catalyst weight. The highest conversion achieved using the biochar catalyst was 43.4% at optimum process parameters. It can be inferred that the biochar catalyst is not effective as an acid catalyst for transesterification reaction.

3.4.Properties analysis of biodiesel

Samples of the biodiesel was taken to test the chemical and physical properties according to ASTM standards.

The result of the analysis is tabulated in Table 5.

Table 5
Physical and Chemical Properties Biodiesel

SL No	Properties	Value
1.	Color	Light Brown
2.	pH	4.5
3.	Kinematic Viscosity	2.81
4.	Density (kg/m ³)	860
5.	Specific Density	0.859

The properties of Biodiesel tabulated in the Table 5 fall under the required range of biodiesel standard

4. Conclusions

Transesterification studies were carried out using KOH and the biochar catalyst. The reaction time, methanol to oil ratio, and catalyst weight were varied individually. A maximum yield of biodiesel of 94.2% was achieved using KOH catalyst. The maximum yield of biodiesel using biochar catalyst was recorded at 43.4%. From this study it can be inferred that the biochar catalyst produced from the chemical activation using H₂SO₄ is successful as a catalyst in esterification process but is not highly effective as an acid catalyst for transesterification reaction. However study showed cashew nut seed shell is a cost-effective and environmentally benign catalyst and a better waste to energy option.

Declarations

Authors Contributions

Vanisree G S, Dr. Aparna K created the concept and Ansuya Paleri interpreted the data. conducted the literature survey and carried out the experiments. Graphical design and manuscript preparation by Vanisree G S.

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Competing Interests

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Figures

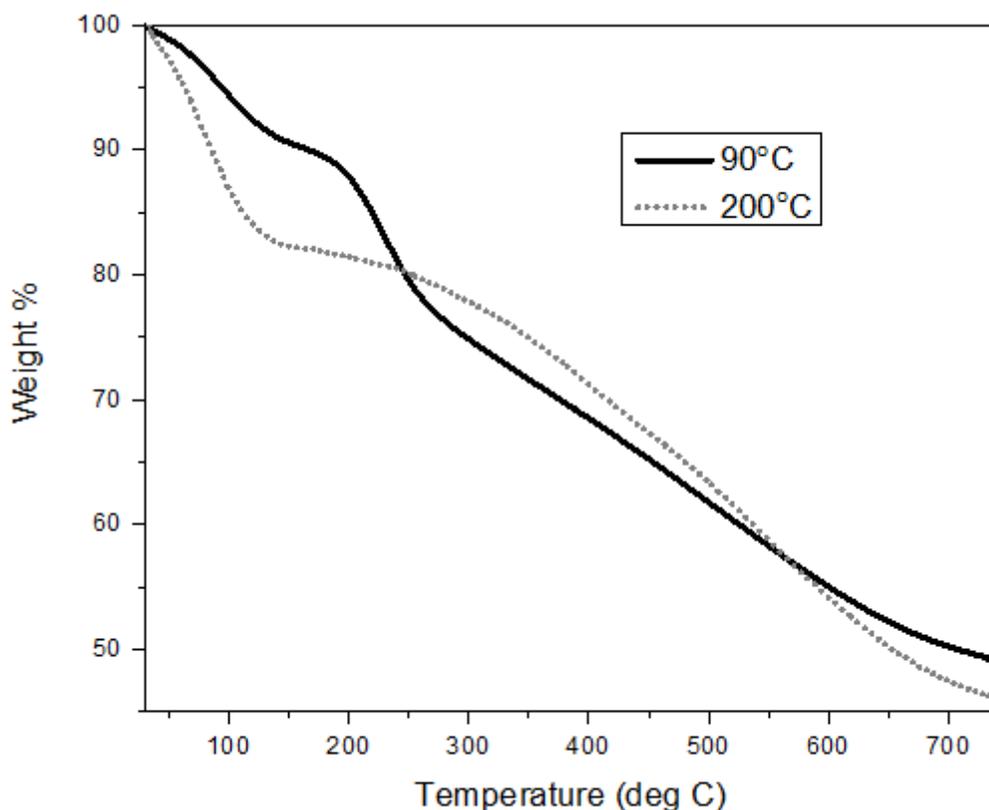


Figure 1

Thermogravimetric analysis of Catalysts

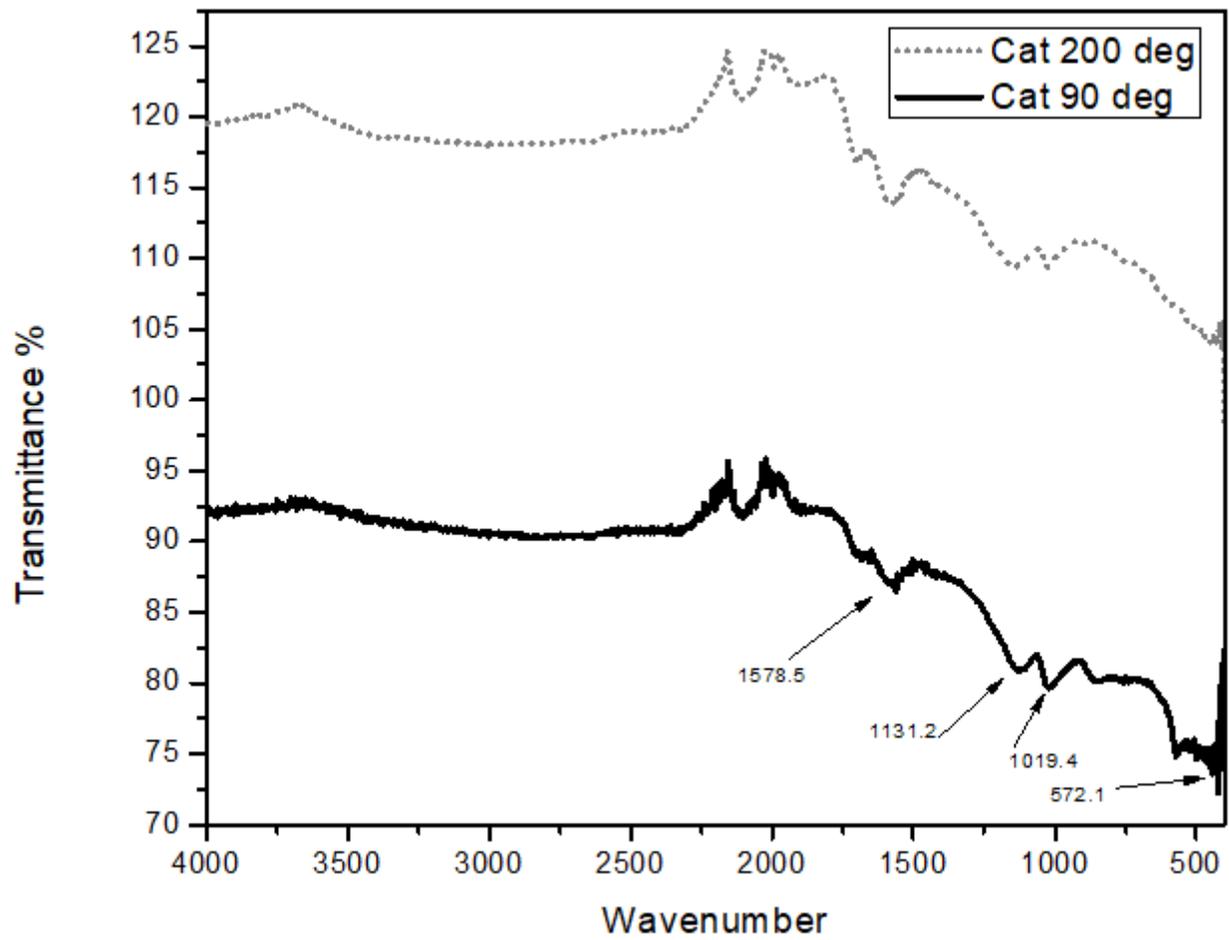


Figure 2

FTIR spectrum analysis of catalysts

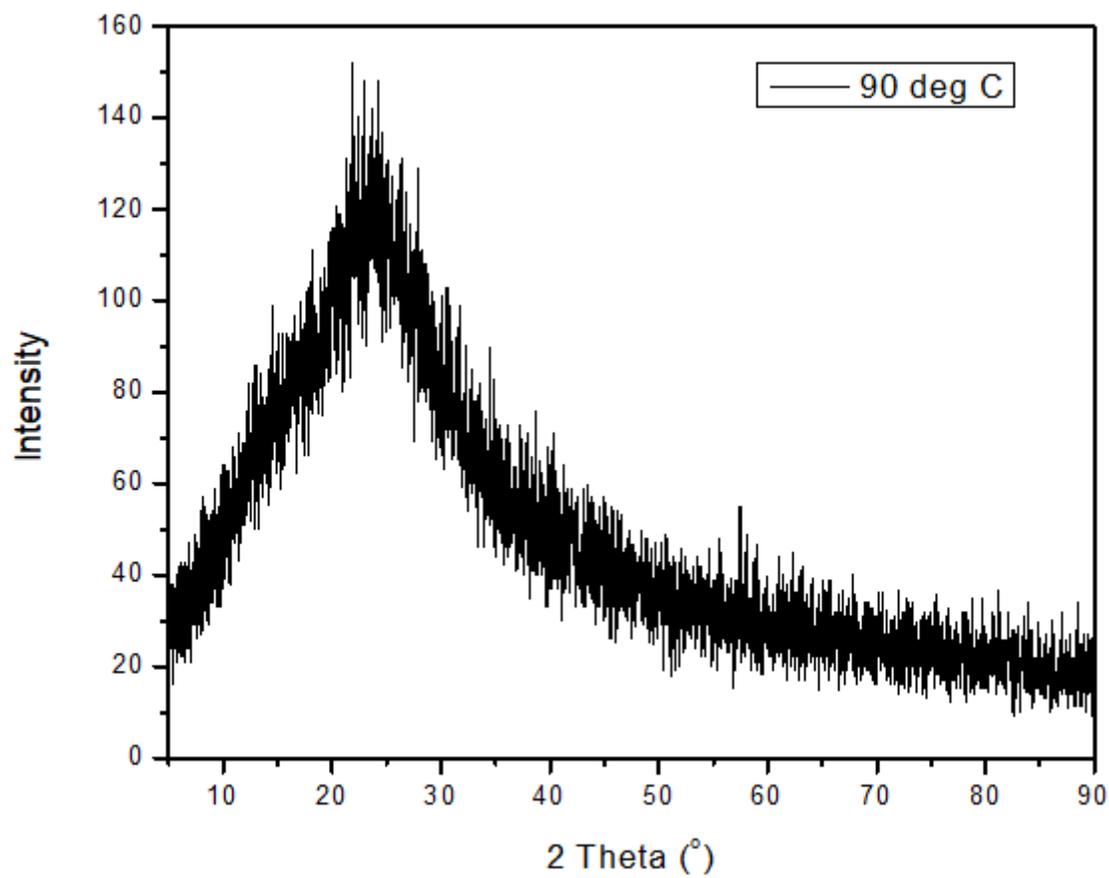


Figure 3

X-Ray Diffraction of Catalyst produced at 90°C

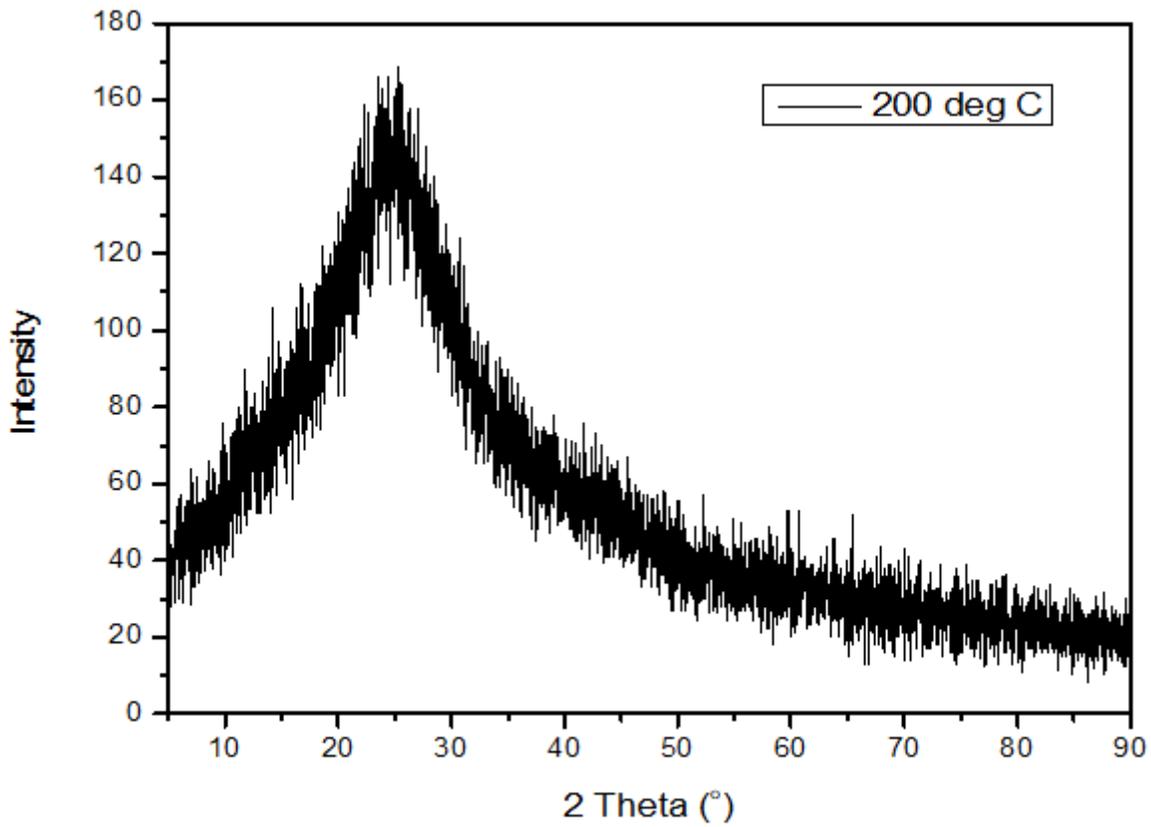


Figure 4

X-Ray Diffraction of Catalyst produced at 200°C

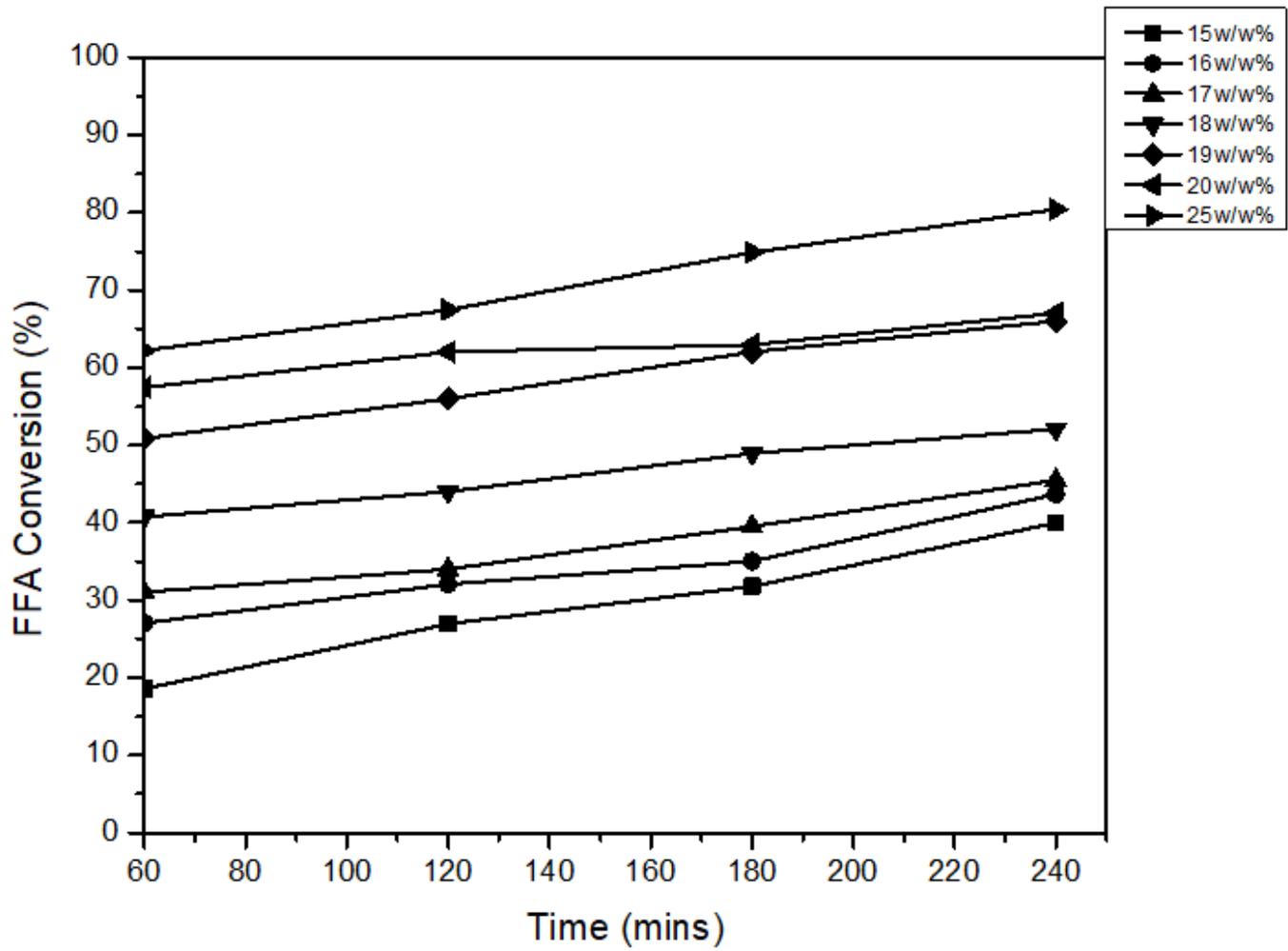


Figure 5

Influence of Catalyst weight and reaction time in the esterification of CNSL

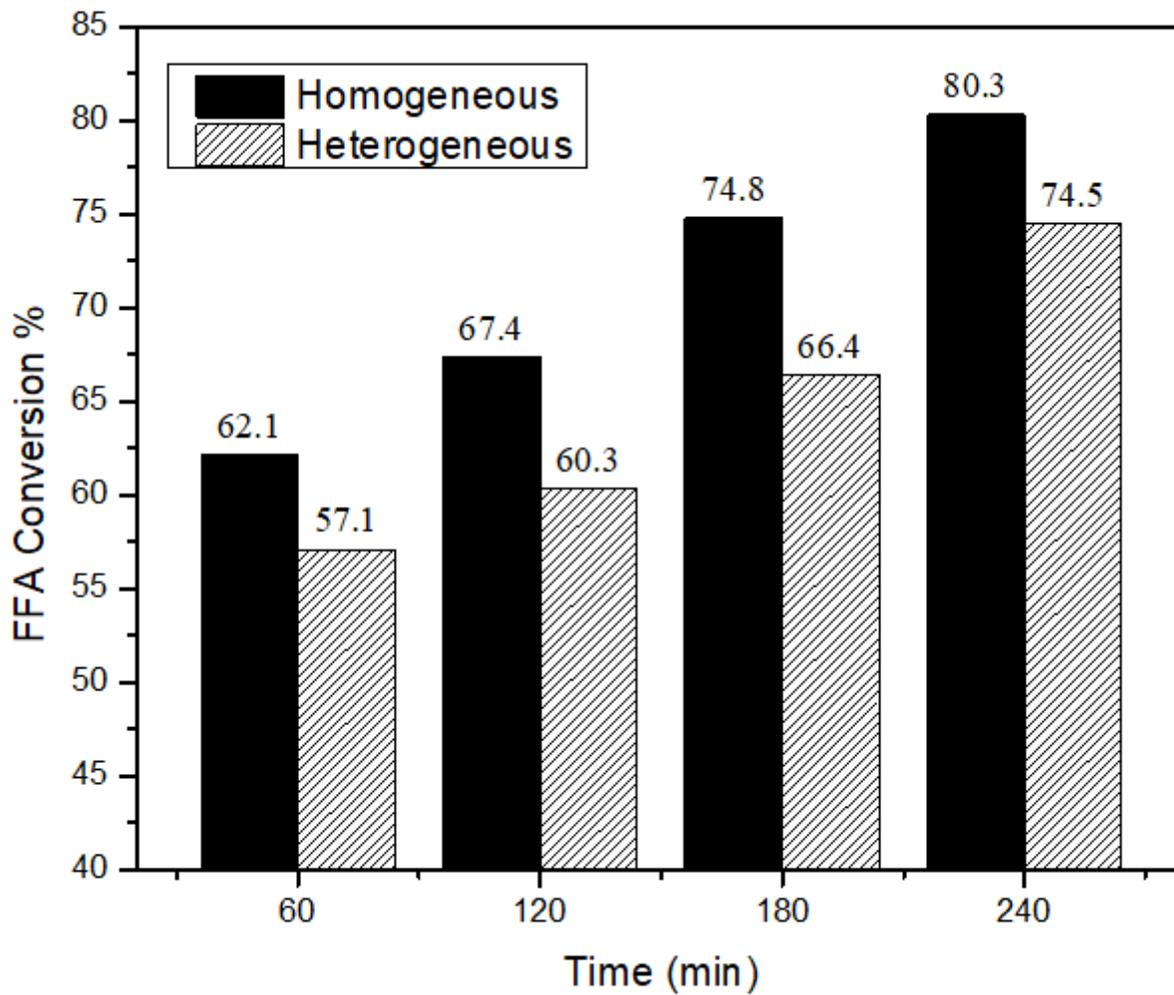


Figure 6

Comparison of KOH and Biochar catalyst in catalyst weight esterification parameter study

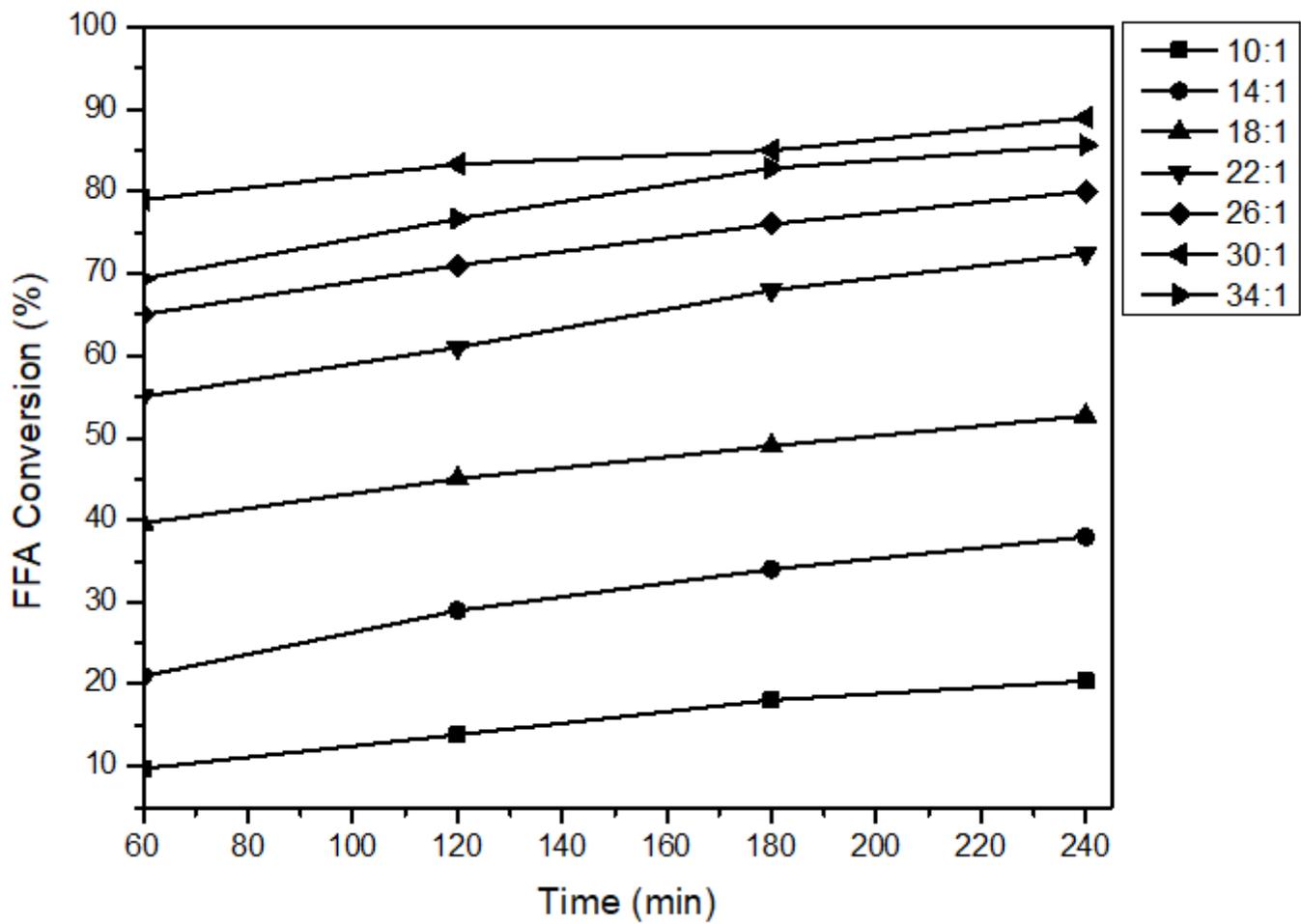


Figure 7

Influence of Methanol to Oil ratio and Reaction Time in the esterification of CNSL

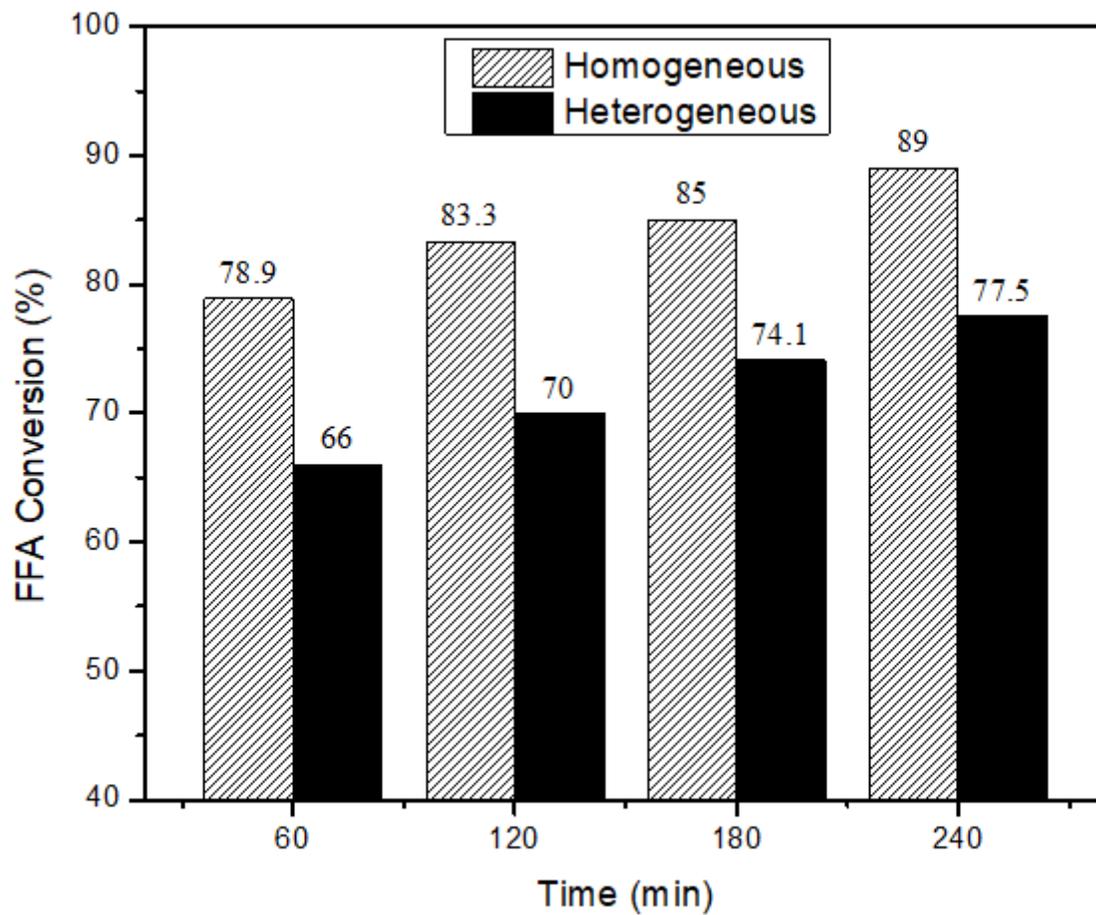


Figure 8

Comparison of KOH and Biochar catalyst in methanol to oil esterification parameter study

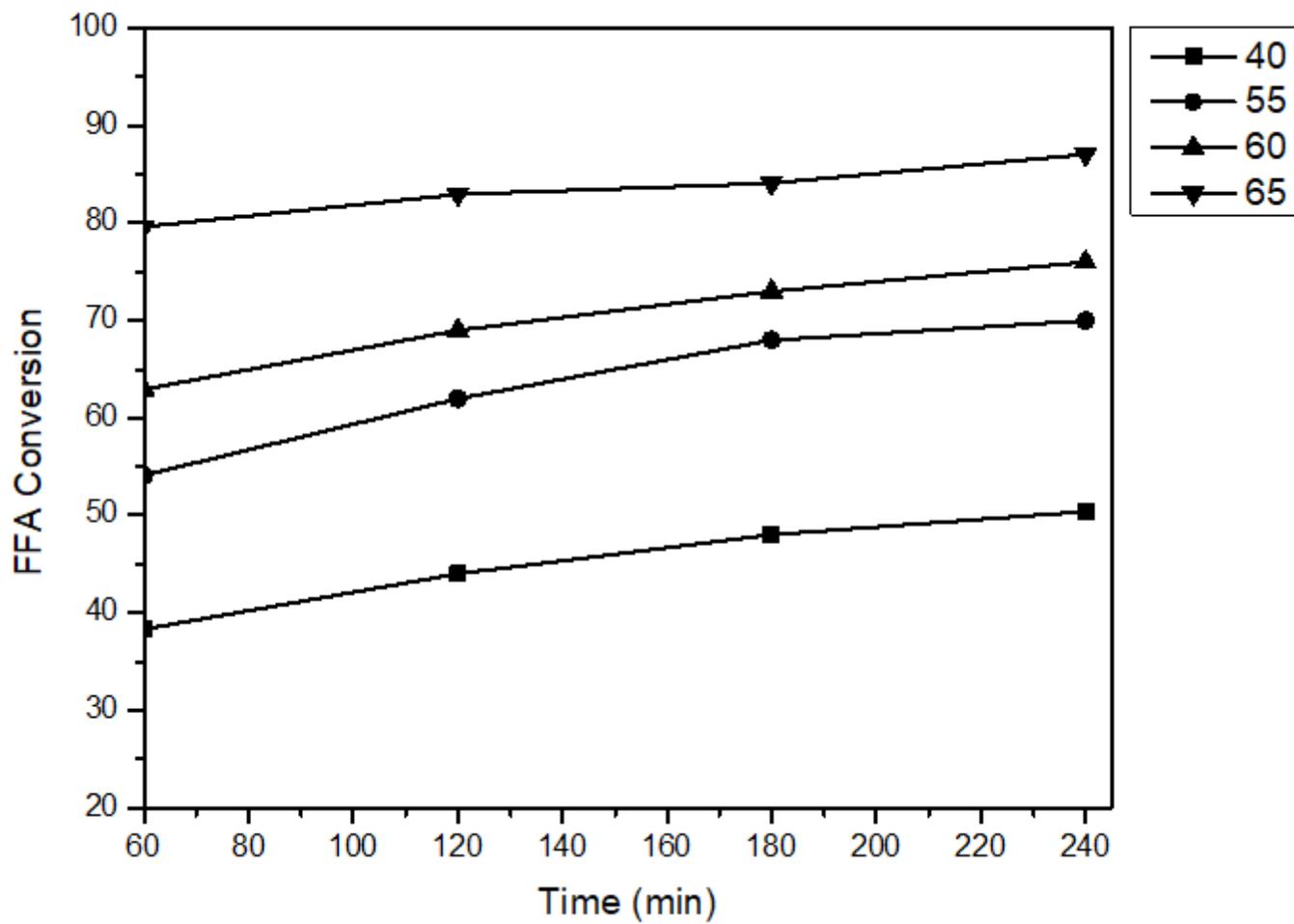


Figure 9

Influence of Reaction temperature and Reaction Time in the esterification of CNSL

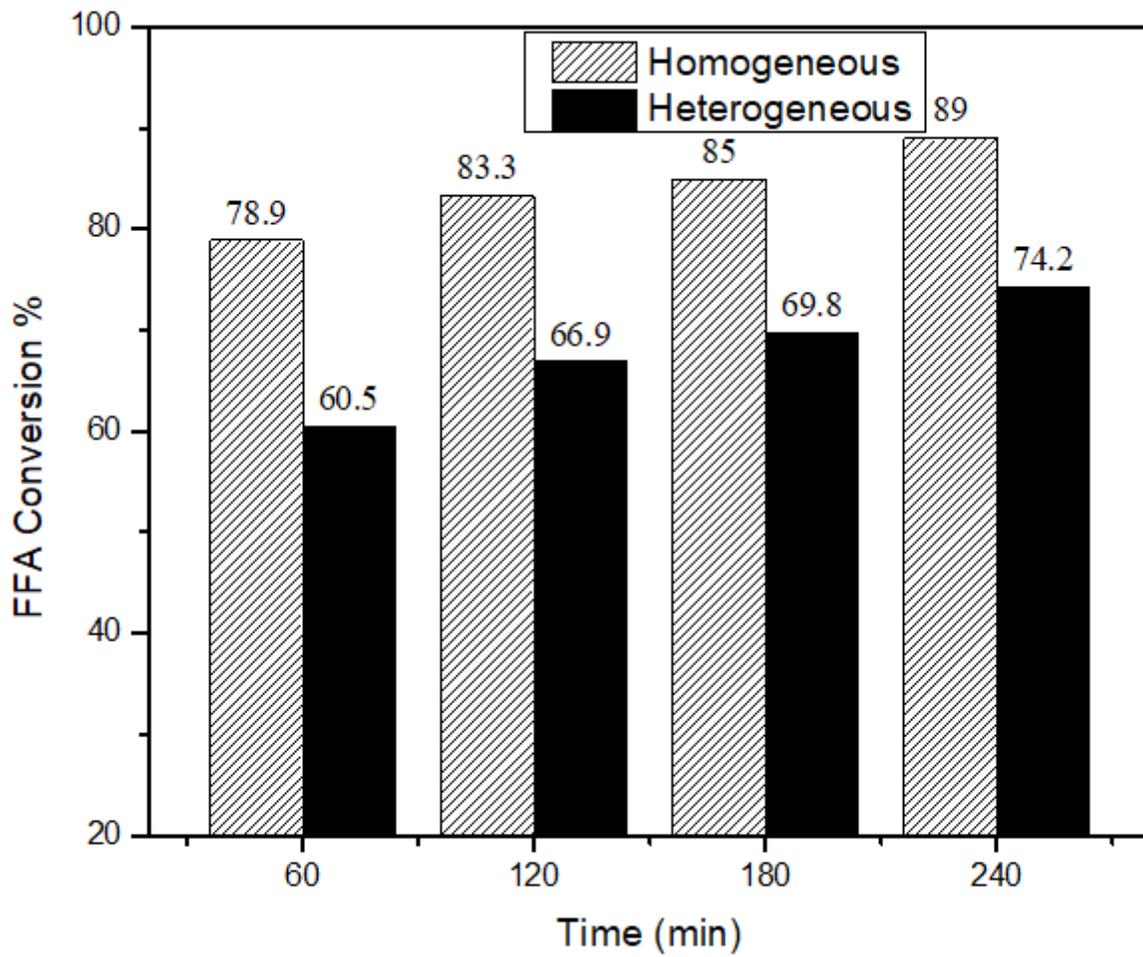


Figure 10

Comparison of KOH and Biochar catalyst in reaction temperature esterification parameter study

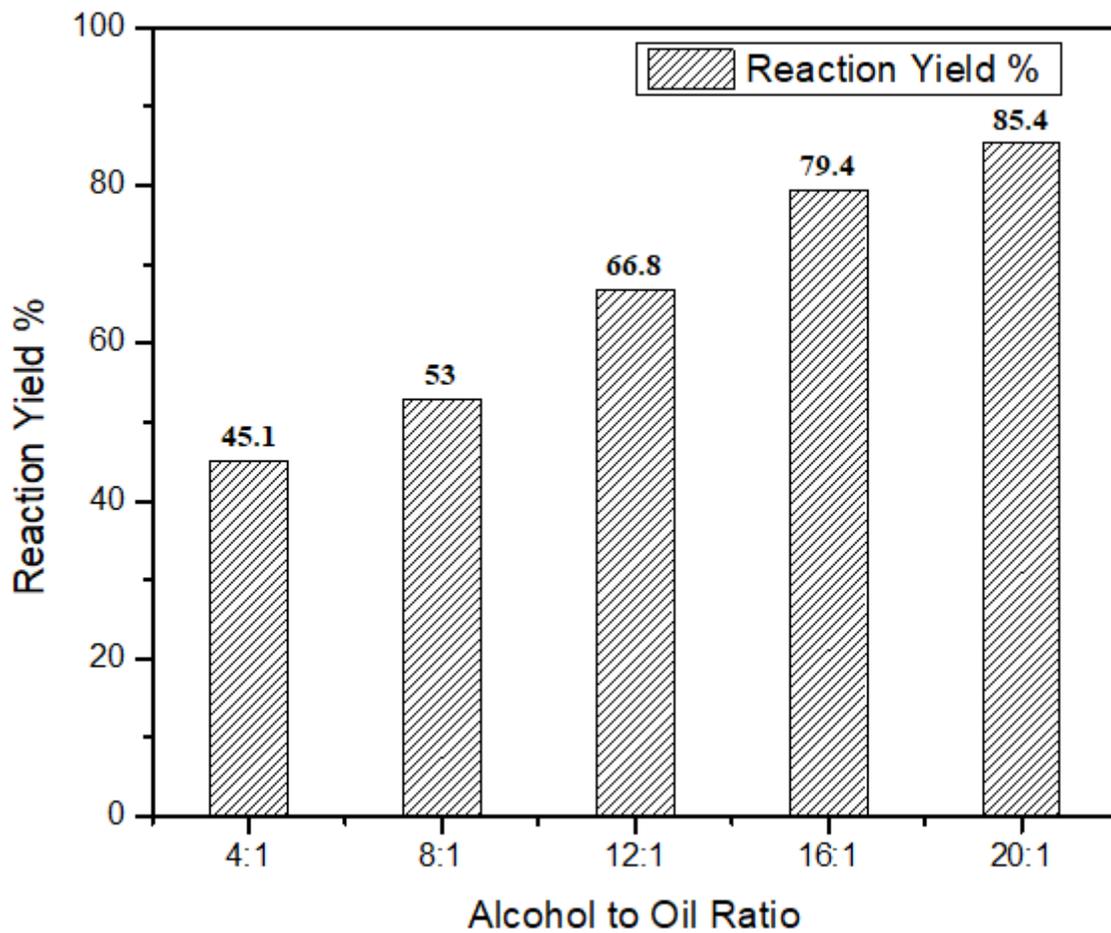


Figure 11

Influence of methanol: oil ratio on biodiesel production using KOH catalyst

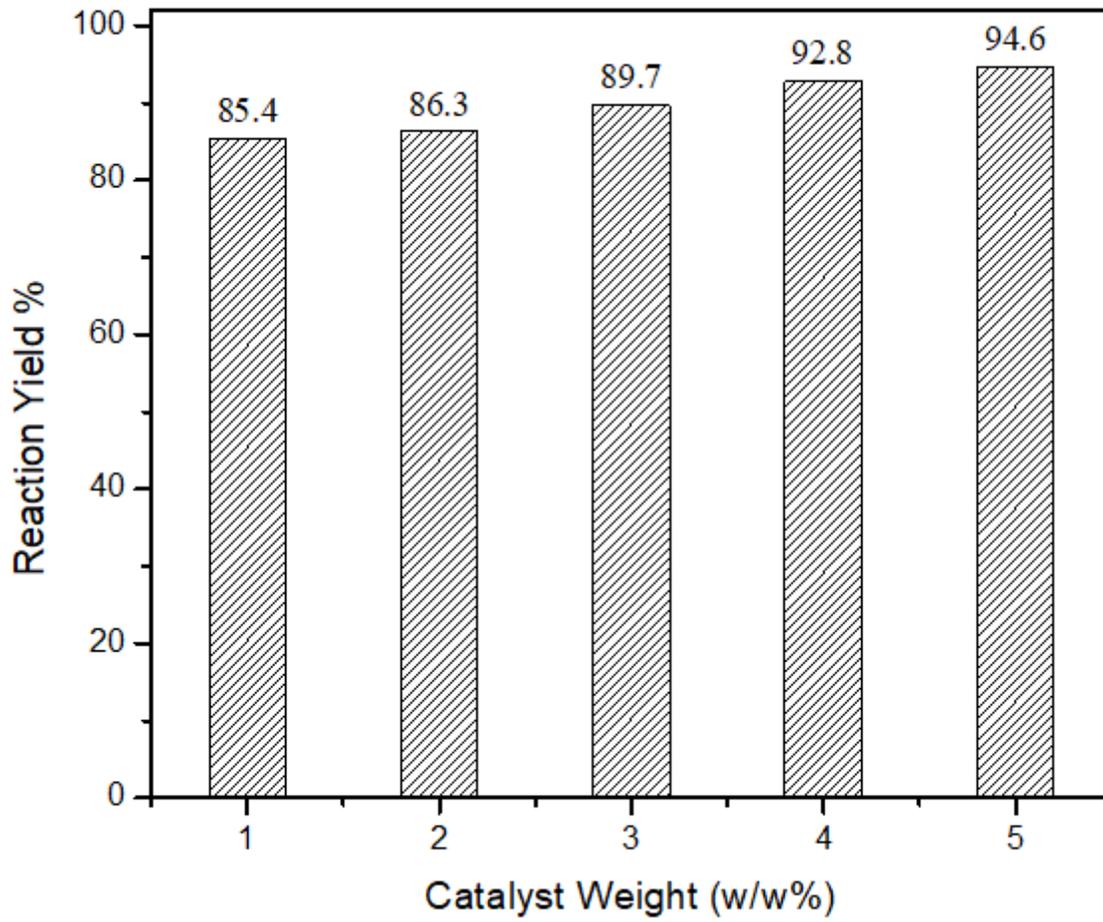


Figure 12

Influence of catalyst weight on biodiesel production using KOH catalyst

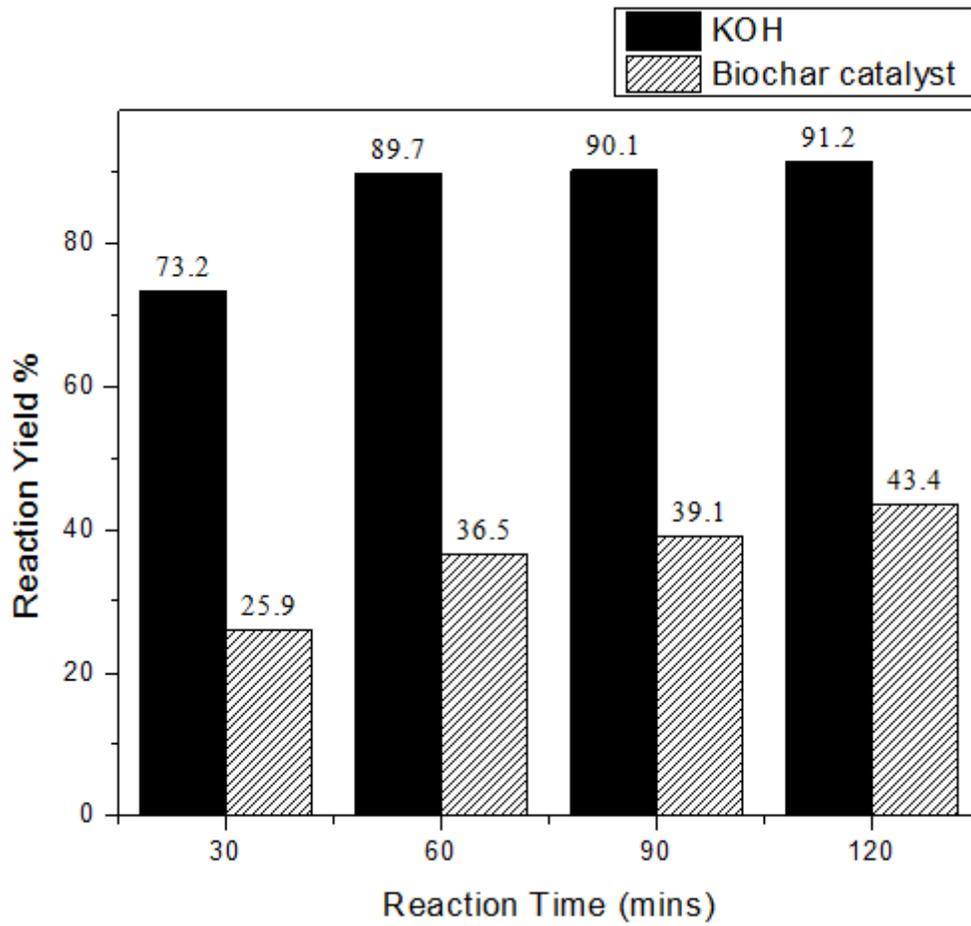


Figure 13

Comparison of Biodiesel yield using KOH and Biochar Catalyst